UNIVERSITY OF SOUTHERN QUEENSLAND

THE DEVELOPMENT OF LEARNING AND TEACHING STRATEGIES AND TECHNICAL TEXTS FOR DIVERSE GROUPS OF ADULT LEARNERS

A Dissertation submitted by

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Abstract

Designing, developing and delivering effective technical education for diverse groups of adult learners is important for both the learners and the future of the technical discipline. The many nuances associated with adult learners, combined with the challenges associated with exploring technically complex topics, make effective technical education difficult to achieve. An understanding of adult learners and teaching, coupled with a robust development framework can help produce effective teaching strategies and technical texts for diverse groups of adult learners.

A literature review focusing on current research regarding adult learners was conducted to investigate some of the nuances of the adult learner. Specifically, the differences between adult learning and child learning were explored which lead to research on the role of experience in learning, the different approaches adult students typically take to learning, and the likely diversity in preferred learning styles within groups of adult learners. The literature review also investigated the role of the teacher in adult education, focusing on the need for learning facilitation in adult education. The desirable characteristics of teachers of adults were also investigated leading to an appreciation of the attitudes, attributes and approaches that teachers can take to enhance the learning experience for adults.

A conceptual framework for the development and delivery of adult education courses was proposed and explained. The framework was based on established complex problem solving principles and covered the entire lifecycle of an adult education course from the identification of a need for a course through to its delivery (and revision). The framework was based on a top-down approach to educational design. This was articulated using a *VEE* diagram that explained how the lifecycle stages (*decision, design, development,* and *delivery*) could build upon one another through concepts such as traceability, ongoing verification and feedback. The principles of adult learning and teaching were integrated into the framework via the activities associated with the design, development and delivery of courses.

The framework, and the information contained in the literature review, has been applied to the development of three different technical courses for three different groups of

adult learners. As a result of the application of the framework and the development of these courses, a number of technical texts has been written and published to support the courses. The adaptability and success of the framework are evidenced by the ongoing and expanded adoption of the courses to support adult education, the publication record being established by the texts, and the positive student and peer review of the adult teaching strategies employed in those courses.

It is concluded that the framework and the analyses arising from the literature review have the potential to be of value and interest to other teachers responsible for the design, development and/or delivery of adult education in technical fields.

Certification

I certify that the ideas, experimental work, results, analyses, software and conclusions reported in this dissertation are entirely my own effort, except where otherwise acknowledged. I also certify that the work is original and has not been previously submitted for any other award, except where otherwise acknowledged.

Signature of Robert Ian Faulconbridge Date

ENDORSEMENT

Signature of Professor David Dowling (Supervisor) Date

Signature of Associate Professor Nigel Hancock (Supervisor) Date

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Chapter 1

Introduction

1.1 Overview

There is still a lot of work to do when it comes to understanding teaching and learning as applied to adult education, with some researchers claiming that we know more about how rodents learn than we do about human learning (Knowles, 1990, p. 11). This dissertation documents selected aspects of current thinking on adult education and learning and shows how this thinking can be used to influence the design, development, and delivery of technical adult education.

The published literature associated with the scholarship of learning and teaching is an enormous body of work that dates back thousands of years. Some of the earliest examples of teaching and learning are provided in the writings of the ancient Greeks and Romans, the Chinese, and also include Biblical figures such as the Prophets and Jesus Christ. For example, a number of Proverbs found in the Old Testament of the Holy Bible (2001) written some three thousand years ago focus on the concept of teaching and learning:

Instruct a wise man and he will be wiser still;
teach a righteous man and he will add to his learning.
(Proverbs 9:9)

Apply your heart to instruction and
your ears to words of knowledge.
(Proverbs 23:12)

Typical quotations from ancient Greece and China also show that the concepts of learning and teaching have been considered for a long time:

"Tell me and I forget. Show me and I remember. Involve me and I understand."
Chinese Proverb (Howe, 2006, p. 102).

Teaching is the highest form of understanding.
Aristotle, 384-322 B.C. (Howe, 2006, p. 105).

Acquire new knowledge whilst thinking over the old,
and you may become a teacher of others.
Confucius, c. 551-479 B.C. (Howe, 2006, p. 111).

Literature relating to teaching and learning comes from a variety of disciplines including psychology, sociology, business, and education. Each discipline and research group tends to adopt their own lexicon, making interpretation and comparison difficult. The focus of the literature is also varied and covers a range of areas such as practical applications, research and academia, and commercial applications. The volume of the literature is also increasing, making it difficult for practitioners to maintain an awareness of current trends and ideas. For example, over the last 30 years, there has been a rapid growth in the literature associated with the field of engineering education.

1.2 Aims and Objectives

The aim of this dissertation is to explore a novel design, development, and delivery framework that has been used for the development of learning and teaching strategies and the associated resources for groups of adult learners. Higher education has been described as a *3-way transaction* between the student, the teacher and the material (Entwistle and Ramsden, 1983, p. 2) and can be illustrated as shown in Figure 1-1.

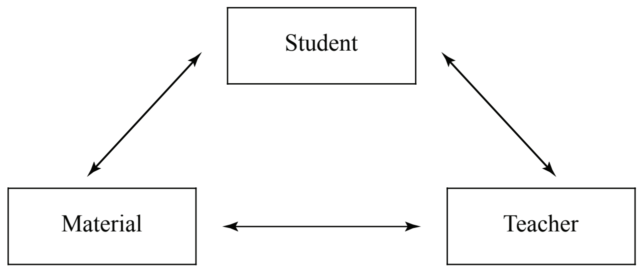

Figure 1-1. Entwistle and Ramsden's 3-way transaction.

Using the 3-way transaction as a basis, the objectives are as follows:

1. *To review existing research and published ideas relating to aspects of adult education and in particular the adult learner.* Chapter 2 therefore explores aspects of students and the way they learn, concentrating on adult learners.
2. *To review what attitudes, attributes and approaches are desirable in the teachers of adult learners.* Chapter 3 examines elements of current research relating to the characteristics of effective adult teachers.
3. *To document a conceptual framework that was developed and then has been applied to the design, development and delivery of technical education to groups of adult learners.* Chapter 4 documents a conceptual framework that was developed to account for many of the aspects of adult learning explored in Chapters 2 and 3 in order to facilitate the delivery of effective educational experiences for adult learners.
4. *To describe and analyse the practical application of the conceptual framework to three different learning environments.* Chapters 5, 6, and 7 report the application of the framework to three areas of technical education: radar systems; avionics systems; and systems engineering. Additionally, Chapters 5, 6, and 7 refer to a body of work published by the author including three technical texts and two co-authored technical texts that have been generated as a direct result of the application of the framework.
5. *To discuss the effectiveness of the framework and the teaching strategies used to deliver technical adult education.* Chapter 8 discusses the effectiveness of the framework and teaching strategies by investigating the ongoing success of the three courses, the publication record of the published works, and student reviews of teaching effectiveness.

1.3 Significant Contributions

This dissertation reports on a number of contributions to adult engineering education in the fields of radar systems, avionics systems, and systems engineering:

- a comprehensive literature review covering critical aspects of adult learning and teaching;
- the development and analysis of a conceptual design, development and delivery framework that can be used along with the literature review to produce and deliver technical courses for diverse groups of adult learners;
- the development of three technical courses that have been delivered to diverse groups of adult learners in the fields of radar systems, avionics systems and systems engineering; and
- the publication of five technical texts (three authored and two co-authored) that have been used in Australia and overseas to support the technical education of adult learners.

Chapter 2

Review – The Adult Learner

The student is one of the three elements in Entwistle and Ramsden's (1983) model and is clearly central to any discussion on education. This section of the literature review therefore focuses on the student as an adult learner. The content and context of this section is illustrated in Figure 2-1. The aim of investigating the student in this way is to identify characteristics of the student that may impact on student learning, the teacher and the course materials in the educational transaction.

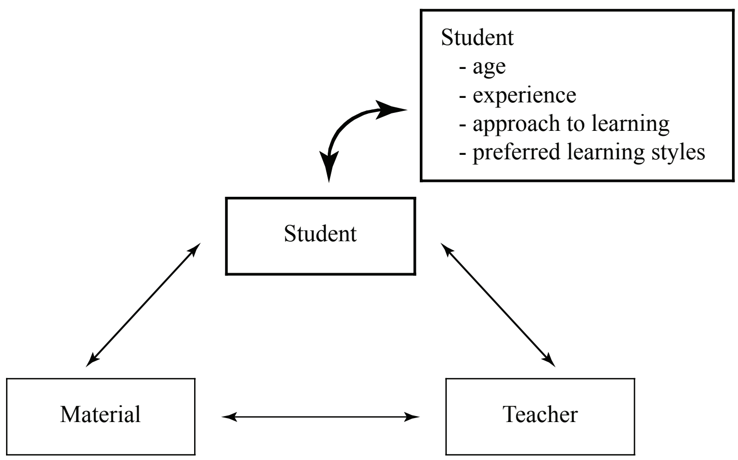

Figure 2-1. Characteristics of the student to be investigated.

The literature documents significant differences between the learning and teaching of adults and that of children. The differences are sufficiently significant to support the development of theories relating to education of children (*pedagogy*) and separate theories relating to the education of adults (*andragogy*).

As we will see, *experience* plays a central role in the differences between teaching and learning in children and adults. The previous experience possessed by adults is of critical importance in defining their learning requirements and attitudes towards learning experiences. Teaching and learning strategies that recognise the importance of prior experience need to be adopted in adult education, and the experience of students should be used as an educational resource.

Research recognises that students may adopt either a shallow (or surface) *approach to learning*, or they may opt to take a deeper, more comprehensive approach. The deep approach to learning is more likely to result in long-term benefit, or change, in the student and should therefore be encouraged.

The way in which students perceive, input, organise, process, and understand information indicates their preferred *learning style*. Every student is different so there is an expected heterogeneity in learning styles in a group. This heterogeneity is likely to be more pronounced within groups of adults. A mismatch between a student learning style and a teaching style is detrimental to the learning experience meaning that both teachers and learners need an awareness of learning styles.

2.1 Introduction to Pedagogy and Andragogy

There is a contrast between educating children and educating adults that needs to be appreciated in order to highlight the unique nature of adult education. The focus of this dissertation is on the education of adults in engineering-related topics. A number of differences between the so-called pedagogical and andragogical models of education are summarised. Each of the elements in the models is discussed throughout this work. Notably, the role of experience in adult learning leads naturally to a discussion of experiential learning, including extant experiential learning processes and models.

2.1.1 Pedagogical and Andragogical Models of Learning

Pedagogy is the art and science of teaching (Knowles, 1990) but has at its roots the idea of teaching children not adults. Adult education has been investigated as an endeavour that is different from general educational theory by authors such as Lindeman (1926, pp. 9-10) who emphasises the very important role of experience in adult learning. He goes on to describe experience as the educational resource of highest value in adult education and calls adult experience as a virtual ‘living textbook’. Jacks (1931, pp. 141-142) also highlights that adult education is different in many ways from teaching younger people. In his description of adults as a neglected species in educational research and practice, Knowles (1990) contrasts pedagogy and andragogy by using six variables, including the role of experience. These differences should be used to inform teaching and learning, and are summarised in Table 2-1.

Table 2-1. The focus of pedagogical and andragogical models.

	Pedagogy (the child)	*Andragogy (the adult)*
The need to learn	Focus is on needing to learn what the teacher teaches them not on how their learning applies to their lives.	Adults need to know why they need to learn, including the benefits of learning and the disadvantages of not learning.
The learner's self-concept	The learner is considered to be dependent upon the teacher.	Adults tend to be self-directing in most aspects of their lives and need to be encouraged to be similarly self-directing in their educational experiences.
The role of experience	The experience of the teacher is critical but the experience of the learner is of little consequence.	Adults' experiences form a rich educational resource that can be drawn on during the learning process. Experiences in groups of adults create heterogeneity in the group.
Readiness to learn	Learners must be ready to learn what the teacher tells them if they want to pass.	Adults tend to be very willing to learn what is important to them at the time of the educational experience. The timing and relevance of the educational experience is critical.
Orientation to learn	Learning is centred on the subject at hand and organised in accordance with the subject matter content.	Adult learning tends to be life-centred, focusing on learning that assists in handling life situations.
Motivation	Learners are externally motivated by marks, teachers' praise and parental pressure.	Internal motivation (job satisfaction, self-esteem, quality of life) dominates adult learners.

(summarised from Knowles, 1990)

Knowles' work in highlighting the important contrasts between teaching adults and children resulted in him being referred to as the *father of andragogy* by some peers (Jarvis, 2004, p. 125). Knowles (1990, pp 55-56) proposes that, from a learning perspective, the transition from child to adult occurs during adolescence and illustrates that by the time learners are around 17 years of age, the andragogical model of teaching and learning is generally more appropriate than the pedagogical model. Knowles, and the researchers he cites, would therefore suggest that in Australia, teaching at and beyond university should consider the andragogical model. Knowles does clarify, however, that he is not advocating exclusively adopting either the pedagogical model or the andragogical model, but rather using the one which is likely to be more generally suitable for a given situation (Jarvis, 2004).

2.1.2 The Need to Learn

Knowles (1990, p. 55) cites a large body of research that suggests that as students get older, the need and desire to learn shifts from teacher directed, that is being told what they need to learn, to being more self-directed. Jacks (1931, p. 149) summarises this point when he says:

> *Nothing can be more absurd than to educate a human being as though he were a pure "mind" or disembodied spirit actuated only by the love of knowledge for its own sake, irrespective of its application in life.*

Adults need to understand why they need to learn something. When they understand the benefits associated with the learning experience and the consequences associated with a lack of learning, they are likely to invest much more in the experience (Tough, 1979). A teacher may be able to assist this process by helping the adult learner transform an education need into educational motivation. In this way, the role of the teacher evolves from that of a teacher to that of a facilitator of learning (Entwistle and Ramsden, 1983); (Biggs, 1987); (Knowles, 1990). In this role, the teacher helps to motivate the learner to learn.

2.1.3 The Learner's Self-Concept

Associated with the evolution from child to adult is taking more responsibility for decisions and actions in all aspects of life. Adult students should, therefore, be more capable than children of being self-directing and self-starting in all aspects of their lives including education. Knowles (1977) warns against assuming that adults will be automatically more self-directing than children as his experience indicates that adults often relate educational experiences with dependency. In this book, Knowles proposes that one of the roles of a teacher of adults is to help them transition from being dependent learners to self-directing learners. Biggs describes adult learners as being more capable, than children, of planning and controlling their learning experiences (1987, p. 91). He goes on to state that this is generally the case even if the adults are less intelligent than the children.

2.1.4 The Role of Experience

The role of experience is perhaps a defining difference between educating children and educating adults. Adults rarely come to an educational experience totally unaware of the material or topics to be discussed. Children, however, may be totally unaware of an issue or situation prior to the educational experience. Within a group of adults, the quality and quantity of experience is likely to be varied, making groups of adults, in particular, more heterogeneous than groups of children (Miller, 1964, pp. 4-5).

The collective experience in groups of adults should be considered to be a valuable learning resource that can be drawn upon throughout the learning experience (Knowles, 1990, p. 59). Knowles warns, however, that the learner's experience may not always be a positive thing associated with adult learning as experience sometimes results in undesirable habits, bias, and presuppositions that need to be adjusted.

The concept of metalearning was first established by Biggs (1985) and is used to describe an educational situation where the student is aware of their learning motives, and has control over their learning strategy selection and deployment (Biggs, 1987, p. 75). Metalearning also requires the student to have the motivation and skills to exercise that control in order to improve their learning. Metacognition occurs when a student thinks about how they learn, but it is when the student uses this thinking to positively change the way they approach a specific learning situation that metalearning occurs (Boström and Kroksmark, 2005). Biggs states that student experience is an important component of metalearning (1987, p. 91) meaning that adult learners are likely to be capable of metalearning. Biggs (1991, p. 53) describes three ways that teachers can assist learners to become metalearners:

- Teachers can assist learners in developing realistic goals and plans for achieving those goals.
- Teachers can assist in developing self-belief in the students by being positive about the students' abilities.

- Teachers can provide constructive feedback to the students and help them understand the value of constructive feedback (rather than seeing it as criticism).

2.1.5 Readiness to Learn

Adults tend to be willing and ready to learn things that they need to know to cope with their current or future situation. Adults see learning as a way of moving from one developmental stage in their lives to the next. It may be necessary to induce this readiness to learn by highlighting the developmental benefits of a learning experience (Knowles, 1990, p. 60).

2.1.6 Orientation and Motivation to Learn

Children are motivated by external factors including praise from their teachers or parents whereas adults tend to be also motivated by internal factors. Adult learners tend to be life-centred, task-centred, or problem-centred when it comes to their orientation and motivation to learn. Learning that is presented in an application context is likely to promote more effective adult learning (Knowles, 1990, p. 63). Tough (1979) found that adult learners are particularly motivated by immediate benefits such as enjoyment, self-esteem, or satisfying curiosity; and by longer-term benefits such as promotion, pay rises, or some other reward. Teachers may be able to use these motivators when helping adult students understand the need to learn as discussed in Section 2.1.2. In 2001, the University of New South Wales (UNSW) conducted a survey of over 2,000 students asking them what they wanted from their university courses (Lee and Trembath, 2002). Students said that they wanted their courses to have practical, relevant, and interesting course content (UNSW, 2002). These are also recurring themes in the student reviews of teachers and courses as documented in Appendix A.

2.2 Experience and Learning

Experience has a role to play in learning situations that involve individual learners with relevant experience, a group of learners with relevant collective experiences, or a lecturer(s) with relevant subject-matter experience. A type of learning called experiential learning occurs when learners are placed in a situation and gain a learning experience from that situation. Experience plays an important role in all learning situations but particularly that of adult learners. Experience and learning, and the nature of experiential learning have been explored by a large number of researchers and authors including Kolb (1984), Jarvis et al. (2005), Jarvis (2004), Johnson et al. (2003), Knowles (1990), Boud et al. (1985), Mezirow (1991), Dewey (1963), Jacks, (1931) and Lindeman (1926).

Each author tends to place his or her own particular emphasis on the definition of experiential learning but the importance of experience is central in each case. For example, Kolb (1984, p. 4) describes experiential learning as the process that links education, work and personal development.

Miller (1964, p. 7) points out that the role of experience is particularly relevant to adult learners as opposed to younger learners because adult learners' experience may in fact define their educational requirements.

2.2.1 Experiential Learning Models

Some of the experiential learning models that have been proposed are quite straightforward and simple. Arguably the most well known is the cycle, described by Kolb (1984, p. 21), as the Lewinian experiential learning model. This is illustrated in Figure 2-2.

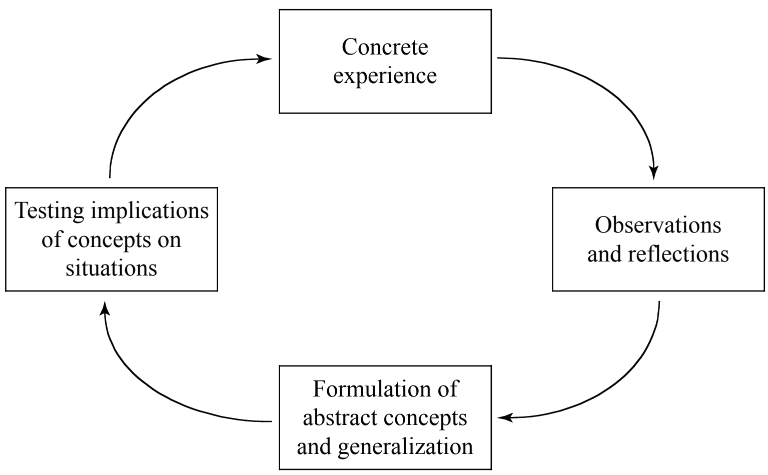

Figure 2-2. The Lewinian Experiential Learning Model (reproduced from Kolb, 1984).

Other researchers have developed more sophisticated models by adding more detail and complexity to the cycle and making it more representative of actual learning cycles. For example, Jarvis et al. (2005, p. 59) produced a learning "cycle" based on a number of surveys and workshops that explored the detailed learning process of the participants. This model is illustrated in Figure 2-3.

Regardless of the model used, experiential learning cycles recognise the prior experience of an individual as they enter a learning experience, and that the learning experience may enhance or change that individual in some way. This enhancement or change might be thought of as the main aim or benefit of the educational experience. For example, Mezirow (1991, p. 7) also talks about experiential learning as facilitating change or movement of an individual toward a more complete and comprehensive appreciation. The concept of education as a means of effecting change in learners is explored in more detail in Section 2.2.2.

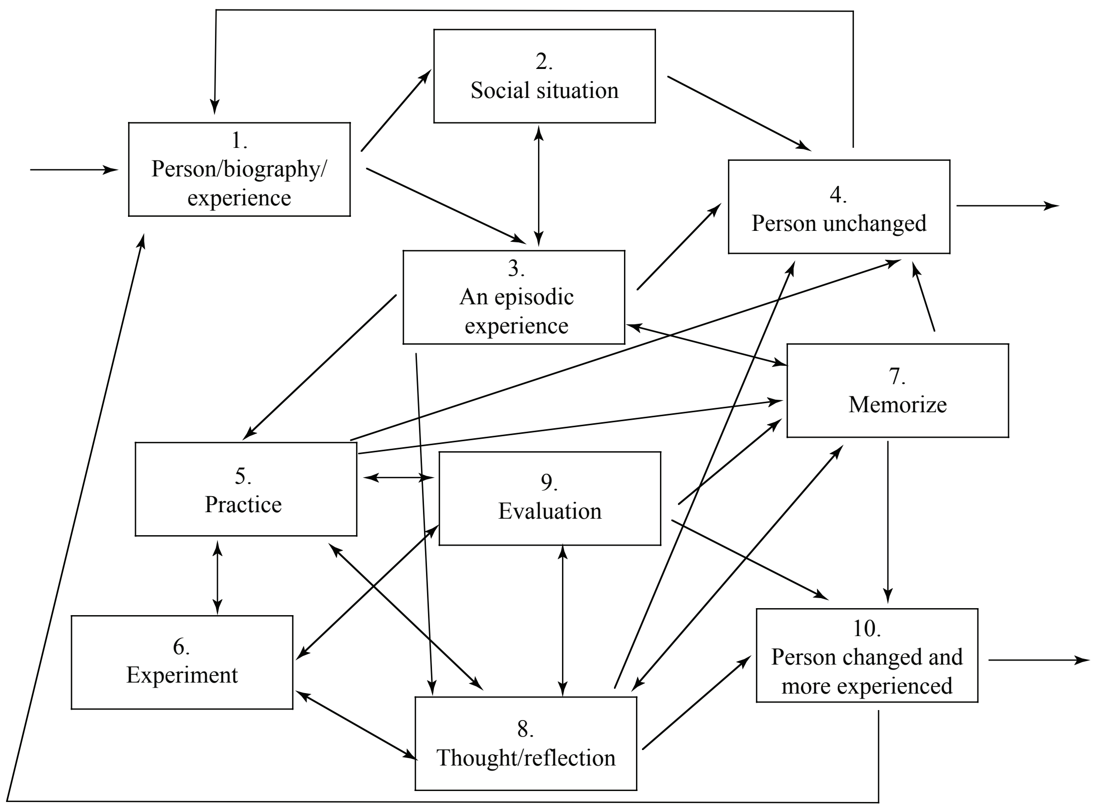

Figure 2-3. The Jarvis model of the process of experiential learning (reproduced from Jarvis et. al. 2005).

The Jarvis model recognises (via) boxes 1 and 2 that an individual comes to the learning experience with some prior background or experience. This situates or prepares the individual in some way for experiential learning. The model also recognises that the totality of experience (shown in box 1) is the background behind an episodic experience (in box 3). This episodic experience can be presented in the form of a learning experience.

Dewey's model as cited by Kolb (1984, p. 23) and reproduced in Figure 2-4 shows experiential learning as being an ongoing process combining observation, knowledge, judgment and impulse. Dewey's model shows one experience leading into another experience and infers advancement with some purpose in mind.

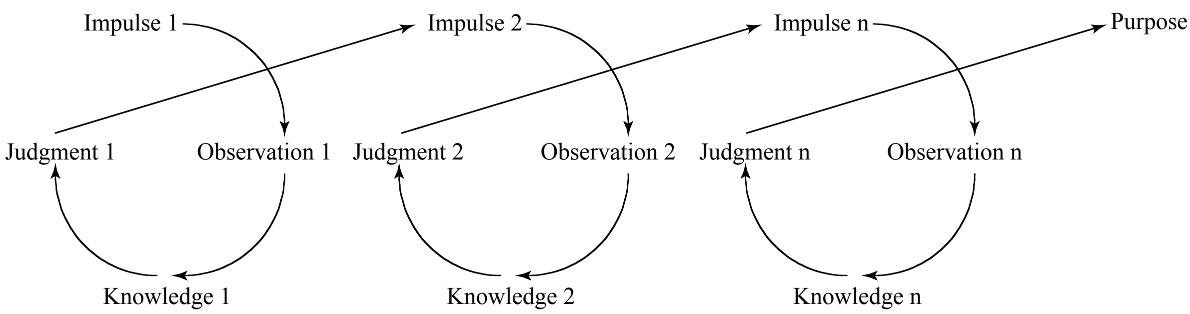

Figure 2-4. Representation of Dewey's Model of Experiential Learning (reproduced from Kolb, 1984)

The ultimate 'purpose' of learning, as described by Dewey, could be to take novices and nurture them through educational experiences into experts. This aim is discussed by Taylor (1994) in his description of a cognitive approach to instructional design called Novex Analysis. Novex Analysis relies on understanding the level of knowledge in both novices and experts with a view to determining what learning outcomes need to be addressed by the instructional designers. Biggs also discusses the ultimate purpose of educational experiences in what he calls the SOLO taxonomy (Structure of the Observed Learning Outcome) that involves progressive transition from incompetence to expertise through a series of stages (Biggs, 1991, pp 12-13).

Defining learning objectives and measuring the learning outcomes of an educational experience may be difficult as it might involve comparing the knowledge, skills and attitudes students brought to the educational experience with their knowledge, skills and attitudes after the experience (MIL-HDBK-29612-2A, 2001). Similarly, Miller (1964, p. 18) considers the benefit of educational experience as being enhancements to cognitive behaviours such as knowing, recognising, attributing meaning, and the performance of intellectual operations. Biggs (1991, p. 17) also believes that the benefit of the educational experience should be measured from the students' perspective by determining whether the students consider the learning experience to have been positive and fulfilling.

When starting out in the specific discipline, the learner may be considered to be a novice. In the case of novices, every relevant experience tends to be a learning experience that moves the learner closer to becoming an expert. Introductory educational activities (such as courses) and episodic work experiences are also bound to provide inexperienced learners with a wealth of new information and experience. Miller (1964, p. 5) recognises this when he contrasts educating children and adults by noting that everything tends to be new to a child, but adults have previous experience that influences their current learning.

As the learner becomes more experienced in the discipline, movement towards *expert* status may slow. This slowing is due to the fact that for more experienced people new episodic and educational experiences are less likely to be completely new. More experienced learners always enter learning experiences with some level of appreciation of the subject area. These learners may have their existing knowledge confirmed rather than changed as illustrated by Box 4 in Figure 2-3. In other cases, the learning experience may require the experienced learners to realign pre-existing ideas (Kolb, 1984, p. 28). Experienced students therefore have an existing knowledge framework upon which they can construct the knowledge gained during educational experiences. More experienced students may be in a position to actively seek information and knowledge to fill perceived gaps (Knowles, 1990). Similarly, more motivated students may tend to seek new professional roles, responsibilities and work experiences that are likely to augment and compliment their educational experiences. This may be absolutely critical to students becoming more expert as the provision of opportunities to practise cognitive skills in authentic work environments is often (pragmatically) beyond most educational experiences (Taylor, 1994).

Despite the aim of education (as far as Novex analysis is concerned) being to take students from novice to expert, students may stall part way along the process and not proceed any further in their development. These stalled learners may:

- reach a point where they are satisfied with their level of expertise;
- have limited access to the necessary practical or educational experience to become more expert; and/or
- change discipline and therefore restart the process.

2.2.2 Learning as a Means of Effecting Change

The theory and definition of learning, according to Knowles (1990, p. 5), is whatever a given author says it is. This seemingly flippant statement recognises the variations and debates that exist over educational definitions and theories. One aspect that seems to unite many authors and researchers, though, is that learning is about effecting change in the learners (Crow and Crow, 1963), (Gagne, 1965), (Hilgard and Bower, 1966), (Knowles, 1990), (Jarvis et al., 2005), (Ramsden, 2003). The main aim of an educational experience is, therefore, to facilitate some change in the learner.

In their simplest forms, therefore, learning processes have an input (an individual's background and biography) and an output (either a change or no change) as illustrated in Figure 2-3. The output from the learning experience then forms the input of the individual's next experience. The idea that learning is a continual process undertaken throughout one's life was introduced by Dewey (1963, p. 35) who stated that:

> *"... every experience both takes up something from those which have gone before and modifies in some way the quality of those which come after."*

This statement also emphasises that current learning episodes position learners to take advantage (from a learning perspective) of future experiences. Tough (1979) also confirms that current educational experiences provide learners with a base to gain further knowledge. Boyle (1982) discusses the concept of continuing and recurrent education within a student's life. His concept incorporates periods of full-time and part time education as discreet activities and shows a change in the student as a result. Boyle's concept is illustrated in Figure 2-5.

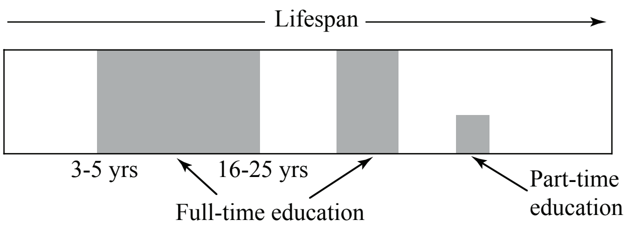

Figure 2-5. Boyle's concept of education (adapted from Boyle, 1982).

Rather than considering experience as being defined by discreet episodes feeding into the next discrete episode, a number of authors consider the change to be a gradual progression from one stage of learning or experience to another. For example, Jacks (1931, p. 147) wrote specifically about adult education as being:

> *"... a sustained process that goes on, that continues to the farthest limits of adult activity."*

He argues that adult education is pleading for *lastingness* and for *continuity*. A possible means of bounding the Jacks' vision of continuity is provided by Taylor (1994) who labels the two extreme positions as 'novice' to 'expert' in his NOVEX model. Biggs (1989) similarly describes a student's progression from 'incompetence' to 'expertise' in his SOLO taxonomy.

Combining the work and ideas of Taylor (1994), Boyle (1982) and Jacks (1931), Figure 2-6 illustrates how the 'vision of continuity' could appear for each learner in a particular discipline. Also included in the figure are illustrations of how episodic (work) experience and educational experience co-exist to move an individual learner along the continuum.

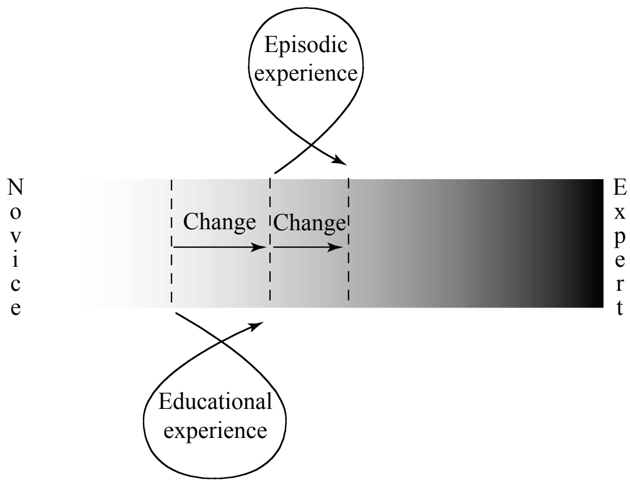

Figure 2-6. Vision of continuity

The vision of *continuity* is useful when acknowledging the previous experience of individual students (especially adult students) and the need for current or future educational experiences. It can also be used to appreciate less experienced students (for example undergraduates) who may be placed closer to the *novice* end of the continuum in their chosen discipline. The concept helps illustrate the role of lifelong experience in progressively developing individuals towards the ultimate goal of becoming expert in a particular field or discipline. The continuum helps illustrate the unifying theme that the aim of education is to effect change in the learner, moving them ever closer to the *expert* end of the continuum in their particular field.

As shown, movement or change can be via a formal educational experience or some form of relevant professional or life episodic experience. The starting position on the continuum becomes the input to the educational experience and the degree of change experienced by the learner determines how far the learner moves towards the *expert* end of the continuum.

Not all learners will benefit from learning experiences. Some learners may remain unchanged, as shown in models such as Jarvis' model illustrated in Figure 2-3. Additionally, it is also conceivable that the educational experience might distort a learners understanding of previous experiences, and changes may therefore be negative as well as positive (Miller, 1964, p. 5).

Another unifying theme from existing educational research is that learning is something done by the student and not by the lecturer in their role as a teacher (Entwistle and Ramsden, 1983). As previously discussed and illustrated in Figure 1-1, Entwistle and Ramsden describe education as being a three-way transaction between the student, the teacher and the subject material.

Each learner will be unique with respect to the experiences they bring to the learning experience. This means that each learner will be at a slightly different starting position on the continuum before the current educational experience. Each learner will also take a potentially different path through the learning journey (Dowling, 2006) due to variables such as learning styles, learning approaches, and prior experiences. Accordingly, it is reasonable to expect that each learner will undergo slightly different degrees of change as a result of the educational experience.

The continuum can be used to visualise situations that result in positive change, negative change, or no appreciable change in the student.

For example, learners who enjoy positive change as a result of their education experience move along the continuum towards the *expert* end of the continuum as shown in Figure 2-7.

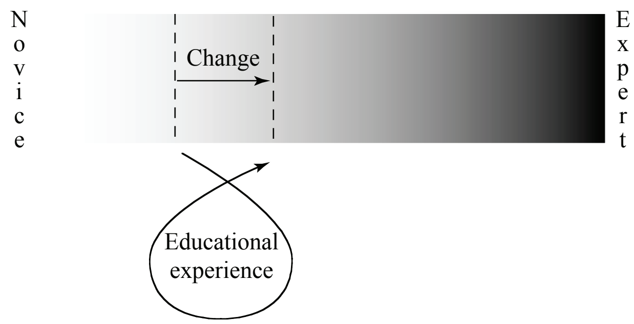

Figure 2-7. Educational experience resulting in positive change.

Learners who suffer negative change as a result of the educational experience may move backwards along the continuum towards the *novice* end, and others may remain unmoved by the experience as shown in Figure 2-8.

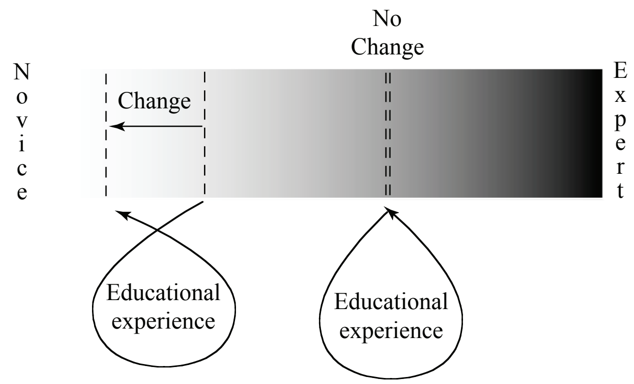

Figure 2-8. Educational experience resulting in negative or no change.

Educational episodes may be self-directed, formal courses, workspace experiences, or professional development activities. People move a certain distance along the continuum each time they are exposed to either relevant experience or relevant education. Subsequent sections of this dissertation describe factors that may determine how much a learner may change due to an educational experience. These are:

- the learner's approach to the educational experience,
- the compatibility between learning and teaching styles,
- the level of (relevant) experience of the learner, and
- the attitudes, attributes and approaches of the learning facilitator.

Given that the aim of education is to move learners along this continuum, it is apparent that educational activities should be designed, developed and delivered with the aim of effecting positive change in the learner. The educational experience should be designed to take individual learners from their current level of experience and move them along their particular continuum to a pre-determined end point. To do that, teachers must understand and define the gap in the learner's experience that the educational experience is aiming to bridge. Additionally, the teacher should account for the educational factors influencing long-term change to the learner to ensure that the gap remains bridged over the long term. The gap between each learner's starting point and the defined end point establishes the training need and helps educators to document the necessary learning aims, objectives, and outcomes for the educational experience. These aims, objectives, and outcomes drive the development of the educational activity. The concept of a training need driving the design and development of educational activities is further investigated in Chapter 4 of this dissertation.

2.3 Student Approaches to Learning

The combination of a student's motive and strategy applied to a specific educational experience is referred to as a student's *approach* to learning (Biggs, 1991, p. 18). Marton is quoted in Entwistle and Ramsden (1983, p. 198) as describing an approach to learning as being a student's response to an educational situation as opposed to a characteristic of the student. Extending that idea, it is not possible to describe a student's approach to learning, only their approach to learning in a specific academic situation (Entwistle and Ramsden, 1983, p. 21).

Considerable research has been conducted on the approaches that individual students use during learning experiences and various researchers have developed their own terminology describing ostensibly similar concepts. Jarvis et al. (2005, pp 61-65) discuss the fact that people do not always learn from experience, but when they do they are largely categorised as either non-reflective learners or reflective learners. Non-reflective learners might be involved in developing specific skills or learning things by rote. Reflective learning is described as a more intellectual approach to learning involving contemplation and the development of hypotheses based on learning experiences. Biggs (1987, p. 2) states that to understand a student's approach, there is a need to understand both strategy and motivation. Rather than use the terms reflective and non-reflective to describe learners' approaches, Biggs (1987, p 70) uses the terms *deep* and *surface*, where deep learners are those who focus on what is meant whilst surface learners concentrate on what is said. He also indicates that learning approaches are something that are relatively stable within individuals, but he argues that learners may modify their learning approach to best suit the assessment regime and subject area (1987, pp 91-94). The concept of students changing their approach to best suit the educational situation is also discussed by Gibbs (1992, pp. 5-11) who agrees that course design, teaching method and assessment determine whether students adopt surface or deep approaches to learning.

This section investigates the literature relating to the approaches that students may take to specific learning experiences and the likely impact of those approaches on the value of the learning experience. It then investigates ways of maximising the benefit of the experience by tailoring the design of the educational activity to encourage students to adopt the most desirable learning approach.

2.3.1 Broad Learning Approaches

There are two broad categories of learning approach proposed by researchers and authors of learning theory: approaches that allow students to develop and change as a result of the learning experience; and approaches that do not support significant and long-term change. Authors tend to adopt their own terms to describe student approaches to learning. Some of the most commonly referenced authors use terms like *non-reflective learning* and *reflective learning* (Jarvis et al., 2005), *formative learning, instrumental learning, transformative learning,* and *emancipatory learning* (Mezirow, 1991), and *surface learning* and *deep learning* (Biggs, 1987; Entwistle and Ramsden, 1987). The terms defined by Biggs, Entwistle and Ramsden are used here.

Entwistle and Ramsden build on Biggs' deep and surface approaches by adding a third classification of learning approach that they call *strategic learners* (1983). They described this category of students as 'game-players' in that these students were focused on what they needed to do to pass or succeed in the course. The authors found that both deep and surface learners may adopt strategic approaches to learning in particular situations. Entwistle and Ramsden (1983, p. 21) use this category because they claim that it is not possible to characterise a student as always taking either a deep or surface approach (to every educational situation), but rather to categorise the approach the student is taking to a particular academic task. Biggs (1987, pp 10-13) describes this third category of learners as *achievers*. According to Biggs, achievers are those learners who tend to adopt an approach to learning that best serves the purpose, where the purpose might be to pass a course or excel in an examination. Achievers are influenced by the course design and especially the assessment. Achievers may adopt a surface approach to learning in courses dominated by traditional examination questions requiring lists and facts to be reproduced. Alternatively, the same learners may adopt a deeper, more reflective style in courses where the assessment rewards those who understand and appreciate the material being assessed.

2.3.2 The Surface Approach to Learning

Gibbs (1992, p. 2) describes surface learners as considering the material they are learning as a series of unconnected facts that must be memorised and reproduced at a later date (usually in an examination of some sort). Surface learners try to anticipate the types of questions they are likely to be asked in the assessment with a view to identifying the information that needs to be memorised (Entwistle and Ramsden, 1983, pp. 16-17). Some researchers believe that there is no place for surface learning approaches in more advanced educational experiences. For example, Gibbs (1992, p. 3) states that it is "disastrous" when students adopt such an approach. He goes on to describe that students adopting surface approaches are unlikely to gain a full understanding of a concept, or grasp key ideas or principles. Rather than state that there is no place for surface learning in advanced educational experiences, other researchers recognise that there are learning situations where a surface approach is suitable. For example Jarvis et al. (2005, p. 63) explain that surface learning can result in change where memorising facts is a necessary part of the learning process. Jarvis cites examples like manual skills training such as those required in assembly line work or children learning mathematical tables. Medical training is another example of advanced education where memory is a critical part of the learning process. Gibbs (1992, p. 4) acknowledges that when factual recall straight after studying is required, surface learning may produce marginally superior results over deeper approaches, but he also observes that this advantage is quickly lost often within a week of the assessment.

Biggs describes the characteristics and attitudes commonly found in surface learners as those who generally:

- *consider the educational experience a demand or an imposition;*
- *consider the experience as a discrete activity being unrelated to other tasks;*
- *worry about the time the educational experience takes;*
- *avoid considering the meaning that the experience may have; and*
- *rely on memorising facts, words and diagrams in order to reproduce aspects of the material.* (Biggs, 1987, p. 15)

Entwistle and Ramsden (1983, p. 97) state that students who adopt a surface approach to learning are generally heavily influenced by their anticipation of the assessment.

2.3.3 The Deep Approach to Learning

Gibbs (1992, p. 2) describes the deep approach to learning as making sense of what is being learnt by considering ideas, concepts, and the structured integration of ideas. Deep learners look for meaning in what they are learning, and actively relate their previous knowledge and experience to the academic task at hand (Entwistle and Ramsden, 1983, p. 16).

Biggs details the characteristics of a deep learner, stating that they:

- *are interested in the academic task and derive some enjoyment from it*
- *search for the meaning inherent in the tasks*
- *personalise the task based on their own experience and the real world*
- *relate the current task to the bigger picture including previous knowledge*
- *try to form hypotheses about the task.* (Biggs, 1987, p. 15)

Entwistle and Ramsden (1983, p. 97) state that students who adopt a deep approach to learning:

- *tend to have a clear intention to try to understand the material and integrate the separate parts of the material together,*
- *attempt to reach their own conclusions, and*
- *and make use of their own experiences in order to integrate their knowledge and understanding.*

2.3.4 Factors Influencing the Adoption of a Learning Approach

Gibbs (1992, p. 9) emphasises that it is not accurate to assume that lazy, stupid, incompetent or unaware students are the only ones to adopt surface learning approaches. In fact, Biggs (1987, p. 93) suggests that more capable students are able to alter their learning approach more so than their less capable colleagues. Gibbs suggests that capable students are making conscious decisions to adopt surface approaches because of inappropriate course design, teaching methods, and assessments. Ramsden (2003, pp 62-63) reinforces this when he describes a student's learning approach as an *intentional phenomenon* where a student acts in such a way as to maximise rewards from the educational system (curricula, teaching methods and assessments) within which they work.

Gibbs (1992, p. 9) summarises the findings of a number of studies into the factors that promote the use of a surface approach to learning:

- A heavy workload
- High class contact hours
- Excessive amounts of course material
- Lack of opportunity to pursue subjects in depth
- Lack of choice over subjects and methods
- Threatening and anxiety provoking assessment

Biggs (1987, p. 95) also explores potential reasons why students who would normally adopt deep approaches to learning may occasionally revert to surface approaches. These include situations where the students temporarily lose interest in their study, are tired or fatigued, are under significant time pressures, or are instructed to adopt a surface approach. Entwistle and Ramsden (1983, p. 22) also state that courses that lack relevance or practical application tend to promote surface approach.

Jarvis et al. (2005, p. 63) states that some adult learners returning to higher education may attempt to use surface learning (or non-reflective learning) in their higher academic pursuits and hints that this is sub-optimal in this context. Cantwell and Scevak (2004) also state that adults with significant work experience returning to formal study may believe in the 'structural simplicity' of knowledge resulting in surface learning tendencies. Students who come to university straight from school are also at risk of adopting surface learning tendencies (Biggs, 1987).

Other research (McMasters, 2006) highlights the important role played by assessment in promoting either deep or surface approaches to learning. McMasters explains that students are aware of the importance placed on results in the form of Grade Point Average (GPA) by both universities and future employers. This forces students to concentrate on achieving a high GPA sometimes at the expense of deep learning. Biggs (1987, pp. 70-71) warns that some assessment methods such as exams requiring reproduction of lists and facts, or multiple-choice questions, promote surface learning by rewarding students who memorise well. Research cited by Gibbs (1992, p. 5) indicates that students, particularly in the science disciplines, are well aware of the differences between surface and deep approaches and vary their approach depending on which approach is more likely to result in success in the form of marks or GPA. This view is also supported by other research (Biggs, 1987, p. 75). These observations help to emphasise the importance of assessment strategies in promoting deeper learning approaches. Unless assessment strategies are well designed, it is possible that students adopting a surface approach to learning can be quite effective (Gibbs, 1992, p. 10). This encourages and reinforces surface learning as the preferred approach. Assessment regimes, therefore, need to be designed carefully to encourage and reward deeper learning approaches.

Biggs (1987, p. 57) suggests, however, that mature-aged students are likely to be achievement driven, that is, they are willing to adapt their style to each course to maximise success. This is because they are motivated by what they have had to give up in order to enter university. The fact that students may be able to change their approach to learning suggests that deep approaches to learning could be successfully encouraged given the appropriate course design and guidance and emphasis from the lecturer. The lecturer may be able to encourage deeper learning by carefully selecting the most appropriate learning materials and resources, and assessment methods, and then discussing the preferred learning approaches with the students. This may result in what has been called meta-learning (Biggs, 1987, p. 75), described by Biggs (1987, p. 75) as being possible when students understand their options with respect to learning and have some control over which approach they apply to a given educational task.

2.3.5 Promoting Deeper Approaches to Learning

Whilst it may be possible for a student who adopts a deep approach to learning to fail to achieve the desired levels of understanding in a given academic task (due to lack of previous knowledge for example), it is not considered possible for students who persist with surface approaches to ever reach a deep level of understanding (Entwistle and Ramsden, 1983, p. 18). Ramsden suggests that it is not possible simply to instruct students to adopt a deep approach to learning (2003, p. 63). To that end, if a deep approach is considered essential to achieve the desired academic outcomes from a task, teaching and learning strategies should encourage and reward students who adopt that approach to learning.

The idea of a relationship between the facts contained in the educational material and the structure of the material can be expressed using the so-called Structure to Fact (S-F) ratio (Biggs, 1987, p. 95). A course in which it is critical for students to comprehend the structure of a subject within which the detail is embedded is said to have a high S-F ratio. Courses, therefore, in which the correct reproduction of facts is more important than structure are said to have a low S-F ratio. Deep approaches to learning are more suited to high S-F courses, whereas surface approaches may be more successful in low S-F courses.

In the case of highly complex and integrated technical subjects (such as radar systems or avionics systems) and deeper engineering philosophies (such as systems engineering), a thorough understanding of the structure and context of the subject area is absolutely critical to an appreciation of individual facts. Learning individual facts alone in these domains leaves the learners with unconnected pieces of information where the overall 'picture' is generally much more important than the sum of the individual facts. Accordingly, complex and highly integrated domains like radar systems, avionics systems, and systems engineering have a high S-F ratio and therefore suit deeper approaches to learning.

When developing teaching and learning strategies, it is important to consider what attitudes learners might have to the given body of knowledge, and what their approach to learning may be. As previously described, surface learning is not considered ideal for complex and integrated subjects like avionics, radar, and systems engineering. Any strategies that may alter these attitudes may assist in promoting deeper learning approaches.

The main reasons why students adopt a surface approach to learning are well understood. So too are the benefits associated with deeper approaches to learning. In developing new courses and course material, a lot can be done to promote deeper learning philosophies. The factors identified by Gibbs (1992) that promote surface learning were listed earlier in Section 2.3.4, and need to be avoided if deeper learning approaches are to be encouraged. The potential problems are repeated below along with strategies to avoid them:

1. **Heavy workloads.** These are an unfortunate fact of modern life. In the academic community, undergraduate engineering degrees are a good example of degrees with heavy workloads and high class contact hours. Excessive amounts of course material also promotes surface learning according to Gibbs (1992) and the researchers he cites. Entwistle and Ramsden (1983, p. 21) refer to this problem as "factual overburdening of syllabuses". Ramsden (2003, pp 70-71) describes the tendency to *overload syllabuses* (and the associated workload and pace issues) as leading to poor approaches to learning. An

alternative to trying to squeeze more into the finite period of time allowed for technical education is to concentrate on the relevant principles, laws, and fundamentals in order to equip graduates with an ability to grasp technology as it emerges. In this regard, the educational experience becomes an enabler that allows learners to move independently and effectively along the continuum of experience into the future.

2. **High class contact hours and excessive content.** Students enjoy the opportunity to pursue subjects in depth or detail. When confronted with a limited amount of contact time, lecturers may opt to cover a lot of material at a summary level rather than more limited topics in increased detail. This issue is related to the previous issues of heavy workloads, limited time, and excessive course material. The research conducted by Gibbs (1992) indicates that a lack of opportunity to pursue subjects in some detail or depth can promote surface learning. Instead of covering a lot of material in limited detail, a broad context could be provided within which fewer topics could be covered in more detail. Assessment strategies may also allow some opportunity for students to explore certain areas of a course in more detail.
3. **Lack of choice.** Students who feel that they have a lack of choice over the subject, or method of study, also tend to adopt surface learning approaches with a view to maximising their chances of success in the subject (Gibbs, 1992). Allowing some flexibility and choice in content, method, and assessment may therefore encourage students to adopt deeper approaches to learning.
4. **Threatening assessments.** Threatening and anxiety provoking assessment systems promote surface approaches to learning (Entwistle and Ramsden, 1983, p. 21). Ramsden goes on to describe assessment methods as being a demonstration of what the lecturer considers to be competence in a given discipline (2003, p. 71). If lecturers are trying to promote deep understanding and critical thinking, the assessment methods need to be aligned with that goal. The idea of using assessment methods that are aligned to professional practice has been suggested as an effective means of making assessment more meaningful or *authentic* (Palmer, 2004).

Biggs (1991, pp. 215-230) has identified four critical elements that promote deeper learning philosophies:

1. **Provide a motivational context**. Students should understand why they need to know something and preferably be actively involved in the learning planning process.

2. **Learner activity**. Students must be active not passive, 'link past with present and future', and learn by doing and then reflecting.
3. **Interaction with others**. Students should be given the opportunity for both hierarchical interaction (with experts in the relevant fields) and lateral interaction with peers. Examples of lateral interaction include learning in groups, student-led tutorials etc.
4. **Well-structured knowledge base**. Subject matter must have a framework that includes logical interconnections. Biggs emphasises that content that is presented and taught in a piecemeal fashion, isolated from other related content, does not support deep learning approaches (1991, p. 220).

In addition, Gibbs (1992, p. 7) links teaching style with learning approaches and describes a closed teaching style as being suitable for surface learning but an open style being more suitable in promoting deeper learning approaches. When using a closed style, the teacher selects the content and delivers to the class. The teacher then tests to ensure that the content has been absorbed. An open style involves the teacher or lecturer acting as a learning facilitator and allows the learners to operate independently within set bounds. The issue of teaching approach is explored in Chapter 3.

As teaching style has been shown to influence the approach students take to learning it is important that teachers recognise the causes and motivations associated with surface and deep learning and attempt to encourage students towards deeper approaches. Teaching style can assist in motivating and inspiring students to become more involved and responsible in their own learning by allowing students to own, engage in, and manage their own learning experiences.

Apart from teaching styles, lectures should consider engaging students in discussions about learning approaches in an attempt to make them more aware of their learning options and the impact of their choices. Biggs (1987, p. 91) believes students are then encouraged to ask themselves:

"How can I learn this more effectively given my intentions, the nature of the task, and institutional requirements."

Biggs then goes on to describe that adult learners are likely to be more self-aware and therefore capable of meta-learning by virtue of the experience they bring to the learning situation. He infers that teachers of adults are able to support meta-learning by taking on a counselor's role in addition to their teaching role. Biggs contrasts the difference between the role and focus of a teacher and those of a counselor by stating that the teacher is more interested in students as a whole (or a group) whilst counselors are more interested in students as individuals (Biggs, 1987, p. 101). This focus infers that teachers focus on external factors such as teaching style and performance of the group as a whole whereas counselors look into internal student factors like individual styles and approaches. A counselor's aim then is to improve the performance of individual students by facilitating and enabling learning. Biggs (1987, p. 112) cites research that indicates improved success when students are encouraged to reflect on their own approaches to learning. By spending some time helping students understand their learning options and explaining why deeper approaches to learning are going to be more beneficial, lecturers may not only improve the learning experience in the short term, but may provide longer term benefits when students apply the same approaches to future educational experiences. Miller (1964, pp. 38-51) reinforces the idea of engaging students about their approaches to learning when he describes some of what he calls conditions for learning. Miller states that students should be made aware of any inadequacy in their current behaviour and have a clear picture of the desired behaviour that they should adopt. They should then be given the opportunity to practice the appropriate behaviour and receive constructive reinforcement and feedback.

2.4 Diverse Learning Styles

The theory and practice of student learning styles continues to generate a huge amount of research, literature and debate, with one recent publication reviewing over seventy documented learning style models or assessments (Coffield et al., 2004a). An appreciation of student learning styles is of critical importance because the impacts of a mismatch between student learning styles and the teaching styles can include boredom, failure and eventual withdrawal from courses (Felder and Silverman, 1988).

The principal aim of this section is to discuss learning style theories and models and to select a valid model that is appropriate for engineering education. The selected model will then be used to investigate the implications of learning styles on teaching styles and strategies. A secondary aim of this section is to recognise the likely diversity or heterogeneity in learning styles within a group of adult learners and then discuss strategies that may be employed to cater for learning style diversity within a group. Therefore, the main focus of this section is on an understanding of learning styles and how this informs the development of teaching strategies and material to maximise the benefits of engineering educational experiences.

2.4.1 Learning Styles and Engineering Education

Individual learners not only take different approaches to learning, they also have individual learning styles and preferences (Kolb, 1984, p. 62). Learning styles determine how students perceive, input, organise, process, and understand information (Felder and Silverman, 1988).

The Felder-Silverman Learning Style Inventory (LSI) (1988) has been selected in this work as a basis of discussion of learning style despite not being analysed in detail by Coffield et al. (2004b). The LSI is focused on learning styles associated with engineering students and is therefore limited in coverage and application as far as the Coffield study was concerned. The Felder-Silverman LSI has been chosen as the basis of this work because:

1. the model is designed specifically to support technical tertiary education in engineering disciplines making it ideal for this dissertation;
2. Felder and Silverman were influenced by the research of some of the pioneers of learning styles theories including Kolb (1984), Jung (1971), Dunn and Dunn (1978), Piaget (1970), and the Myer-Briggs Type Indicator (MBTI);
3. the model has been validated and applied by a number of researchers and practitioners including Livesay et al. (2002), Zywno (2003), and Parvez and Bank (2007); and
4. the model has received an enormous amount of attention since its original publication nearly 20 years ago as described by Felder (2002) in a recent 2002 preface to his 1988 paper. In the 2002 preface, Felder states that the web-based learning style self-assessment tool based on the LSI receives around 100,000 hits per year and has been translated into a number of different languages.

In Felder and Silverman's LSI, a number of learning styles or dimensions were identified to describe a learner's preferred way of dealing with information. Each of these dimensions has a pair of extremities between which each individual learner sits. Felder and Silverman (1988) define the dimensions and the poles of those dimensions as they apply to engineering education as follows:

- **Perception,** which ranges from:
    - Sensors who like facts, data and experimentation, to
    - Intuitors who prefer theories and principles.
- **Input,** which ranges from:
    - Visual learners who prefer pictures, diagrams, and graphs, to
    - Verbal learners who prefer verbal and written communication.
- **Organisation** of the information, which ranges from:

  - Inductive learners who like to start with concepts and ideas and infer facts from these, to
  - Deductive learners who start with the facts and deduce the concepts.
- **Processing** of the information, which ranges from:
  - Active learners who like to discuss, argue and test ideas, to
  - Reflective learners who prefer to consider the information privately.
- **Understanding** the information, which ranges from:
  - Sequential learners who prefer the information to be logically ordered and presented, to
  - Global learners who learn in a more unpredictable fashion.

Felder and Henriques (1995) clarified and revised the original 'auditory' style (Felder and Silverman, 1988) to 'verbal' to recognise that learners preferring written words are considered verbal learners, not visual learners. This resulted from studies conducted by cognitive scientists cited by Felder and Henriques that indicate learners normally convert written words into their own voice and process them in the same way as actual spoken words. The authors also omitted both the concept of kinesthetic learning, and the inductive/deductive learning style from their model. Kinesthetic learning is associated with information perception through touching, tasting and smelling, and information processing via moving, relating, or doing something active while learning. Felder and Silverman argue that kinesthetic learning is only marginally relevant to professional-level engineering education and therefore omit it from their model. In the preface to the original paper, Felder (2002) discusses that although inductive and deductive learning are indeed valid learning styles, inductive teaching styles are preferred over the more traditional deductive styles leading to the omission of this dimension from the more recent LSI.

One of the strong suggestions from Felder and Silverman is that teachers need to be aware of the learning styles of their students and be accommodating of those styles in the development and delivery of course material. Felder and Silverman (1988) lament the loss of many potentially great engineers who may have dropped out of engineering courses because their learning styles and classic engineering teaching styles were misaligned.

Information on how individual students learn is typically collected by asking the student a series of exploratory questions. The answers allow a series of scores to be calculated and then plotted on a graphical representation like the one shown in Figure 2-9.

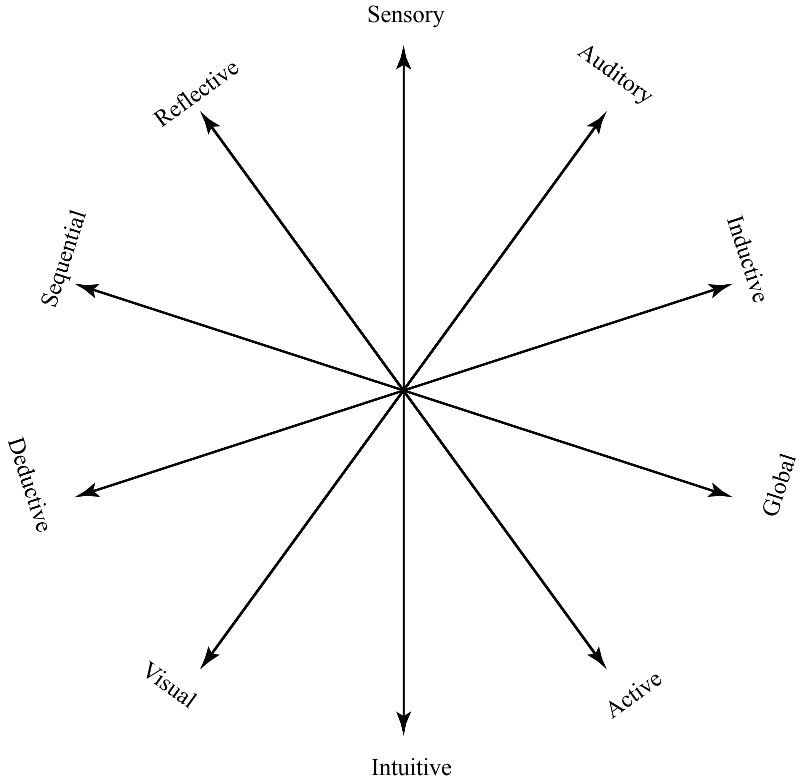

Figure 2-9. Felder's Learning Styles.

2.4.2 Learning Style Diversity in Adult Students

There are acknowledged differences in typical learning styles between students studying engineering disciplines and those studying non-technical disciplines (Felder and Spurlin, 2005). This suggests that courses, course materials, teaching styles, and assessments designed for engineers may not be suitable for non-engineers. In addition to the likely differences between students from diverse disciplines, Kolb (1984, pp. 78-95) also states that it is possible to generalise about students' learning styles based on personality type, professional career choice, current job role, and other basic student attributes. For example, Felder and Spurlin (2005) cite a number of studies in which the LSI (discussed in 2.4.1 and illustrated in Figure 2-9) was used to determine the preferred learning styles of groups of engineering students. The results cited were collected across a range of institutions, engineering disciplines and year groups and indicate that groups of engineering students typically contain:

- a small majority (approximately 60%) of *active* learners with the remainder being *reflective* learners;
- a majority (approximately 60%-70%) of *sensing* students with the remainder being *intuitive* students;

- a strong majority (over 70%) of *visual* learners with the remainder being *verbal* learners; and
- roughly equal numbers of *sequential* and *global* learners in the group.

It must be emphasised that although surveys of groups of students may confirm ‘typical’ learning styles for different groups of students, these results represent average responses. Kolb (1984, p. 63) warns against using these sorts of results to deny human individuality in learning styles as there may well be no ‘typical’ student within the group. Each student brings different learning styles to the classroom and it is therefore too simplistic to assume that every student in a group of engineering students, for example, has the same learning styles as a ‘typical’ engineer. Additionally, when dealing with adults who come from a diverse range of backgrounds and experiences, there is likely to be additional significant learning style variation across the group (Knowles, 1990).

Due to the likely diversity of learning styles within groups of learners, the approach to teaching must include elements of each teaching style to accommodate the different learning styles. The need to align teaching styles with diverse learning styles is explored in Chapter 3.

2.4.3 Additional Benefits Associated With Learning Style Awareness

Given the likely diversity in preferred learning styles within a given group of adult learners, an accommodating teaching strategy is critical to positive student learning. However, there are additional benefits associated with an awareness of learning style diversity that can enhance the quality of educational experiences.

2.4.3.1 Student Self-Awareness

Students should understand and appreciate their own personal learning styles and the impact these styles have on their learning experiences (Kolb, 1984, p. 62). There is debate in current literature about whether students can change their learning styles to adapt to different educational situations (Coffield et al., 2004b), but Kolb (1984, p. 77) cites research indicating that basic learning styles remain highly stable from early years through to adulthood. Regardless of whether students can adapt or not, they will have learning style preferences. An appreciation of learning styles and the corresponding teaching styles allows students to understand why they might be excelling in some areas whilst struggling in others. This may result in them developing strategies to cope when using non-preferred learning styles, and the difficulties that arise, rather than losing confidence in their own abilities. There may be benefits if lecturers and students spent some time together understanding learning styles and teaching styles with a view to achieving balance and alignment. Perhaps learning style assessments such as those referred to in Section 2.4.2 could also be used to help raise student awareness of their own learning styles.

2.4.3.2 Creating a Common Learning Style Lexicon

Coffield et al. (2004b) list and explore a very large collection of terms and meanings associated with learning styles generated by different researchers from different disciplines, often describing ostensibly similar concepts. This leads to a large and potentially confusing learning style lexicon. A defined lexicon is absolutely critical to have meaningful discussions between learners and teachers about learning, and to promote student learning style self-awareness (Leat and Lin, 2003). By selecting and applying an appropriate learning style model, both teachers and students are able to engage in meaningful discussions from positions of mutual understanding.

2.4.3.3 Deliberate and Controlled Mismatching of Learning Styles

There is some research indicating that there may be benefits (in terms of stretching and challenging students, and relieving boredom) in deliberately mismatching teaching styles and the known learning styles of the group. For example, Grasha (1984) questions whether students become bored in learning environments that match their learning styles, indicating that some mismatching might be constructive. Vermunt (1998) describes the concept of constructive friction in learning styles where students are urged to take more responsibility for the content, processes and outcomes of their educational experience. Kolb (1984, p. 203) discusses the possibility of personal growth and creativity resulting from mismatching learning and teaching styles. Brookfield (1995, p. 59) states that sometimes the last thing learners need is for their preferred learning style to be continually re-affirmed, and that letting learners learn only with their preferred style can seriously limit their development as learners.

Mismatching needs to be carefully controlled to avoid the well-established problems caused by inadvertent misalignment described by Felder and Silverman (1988).

2.5 Conclusions

This chapter concentrated on aspects of the adult student.

The contrasts between adult students and younger students were discussed in the section on andragogy versus pedagogy. A model describing andragogy highlighted some of the unique elements of teaching adult learners that should be considered during the design, development and delivery of adult education. The andragogical model highlighted: the importance of establishing a need for the education, a need that the adult learner could commit to; the idea that adult learners take more responsibility for their learning; and the importance of readiness and motivation to learn.

One of the defining differences between children and adults when it comes to learning is the range of experience that adults are likely to bring to learning. The role of student experience in adult learning is important as it may define the students' educational requirements and influence how adult students perceive the educational experience. In groups of adults, there may be considerable relevant experience that can be considered an important learning resource by the teacher. This student experience can be used to engage the students, demonstrate the relevance of the topics, and promote discussions within the class. Experiential learning models were discussed and the concept of learning as a means of effecting change in the learner was introduced. This led to a discussion of the concept of education as a vision of continuity with adult students being placed on a continuum somewhere between novice and expert in a given discipline or field.

Approaches to learning were discussed, and two broad approaches to learning were described. Although it has been determined that there are learning situations where surface approaches are suitable, it is the deep approach to learning that is longer lasting and more suitable to learning about complex and integrated topics such as radar systems, avionics systems and systems engineering. The reasons why students adopt either the deep or surface approach were investigated with a view to understanding how teaching strategies may be used to encourage deep approaches to learning. It was also suggested that lecturers should take on more of a counselor or mentor role in an attempt to raise student awareness of learning approaches, and encourage the concept of student meta-learning.

The concept of student learning styles was discussed, as was the likely learning style diversity within groups of adult learners. A learning style model designed for engineering students was described as a way of classifying the preferred learning style of individual students. Teachers could use this model to understand better how students learn with a view to employing appropriate teaching styles. Students, too, could use this model to better understand how they learn as individuals.

Chapter 3

Review – The Teacher of Adults

Chapter 2 concentrated on adult learners and how they learn, and how teaching may impact on student learning. A firm intellectual grasp of the course content by lecturers is vitally important to the student learning experience, and the ability to communicate well-planned and organised course material also enhances the learning experience. However, there is increasing evidence to suggest that technical mastery by the teacher, good course materials, and the ability to communicate effectively are not enough to ensure achievement of desired learning outcomes. Figure 3-1 illustrates the aspects of the teacher of adults to be investigated in this section of the literature review, and how that relates to the educational transaction.

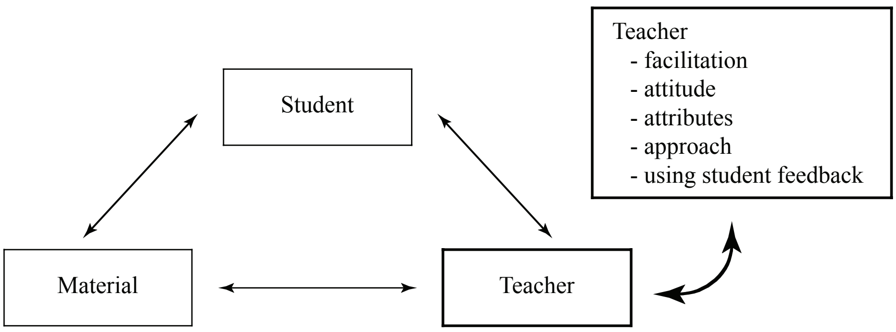

Figure 3-1. Aspects of the teacher to be investigated.

This chapter focuses on the teacher's role in the education of adult learners. This chapter does not aim to explore what tasks a good teacher should be performing, but concentrates on the humanistic side of teaching adults and explores the role of a teacher as a *learning facilitator*. Accordingly, the chapter concentrates on the *attitudes*, *attributes* and *characteristics* of excellent adult learning facilitators that set them apart from other teachers. Research indicates that the personal qualities, skills, teaching philosophies, and attitudes of the lecturer have a major bearing on the learning experience from the learner's perspective (Tobin and Fraser, 1988); (Knowles, 1990) (Jarvis, 2004). There is also a ubiquitous belief that a student's interest levels and approach to learning will be directly influenced by factors such as the interest the lecturer has in the topic, the lecturer's enthusiasm, and the ability of the lecturer to create stimulating experiences (Ramsden, 2003, pp. 72-73).

3.1 The Teacher as a Learning Facilitator

Biggs (1991, p. 2) cites research that emphasises that the learner is the one that needs to construct knowledge, not the teacher who imparts that knowledge. He then goes on to describe three levels of teaching:

- Level 1 – involves a competent teacher with sufficient content knowledge and an ability to present fluently this knowledge.
- Level 2 – involves a Level 1 teacher who is also equipped with sufficient teaching skills to adapt to the needs of individual students.
- Level 3 – involves Level 1 and 2 skills but also takes on the role of a student-centred learning facilitator (which involves understanding things from the learner's perspective).

It is in the description of Level 3 teaching that the term *learning facilitator* is used rather than lecturer or teacher. Entwistle and Ramsden (1983) also emphasise that the purpose of teaching is to facilitate learning because it is the student who actually does the learning not the teacher. Ramsden (2003, pp. 108-114) also describes three teaching theories that are very closely aligned with Biggs' three teaching levels. The theories are those types of teaching typically subscribed to by university lecturers:

- Theory 1 – teaching as telling or transmission
- Theory 2 – teaching as organising student activity
- Theory 3 – teaching as making learning possible

Rogers (1951) also developed a concept similar to level 3 or theory 3 teaching that he called *student-centred teaching*. Student-centred teaching recognises that a student cannot be taught directly, but merely facilitated in their learning.

Teachers can help learners in their learning journey by being a role model in terms of how to interpret information, understand and comprehend that information and solve problems using the information (Biggs, 1991, p. 138). Helping students through their learning journey may involve both teaching roles and educational counseling roles as described by Biggs (1987). A key to this role may be the ability of the teacher to place himself or herself in the position of the learner.

3.2 Facilitating Learning in Adult Learners

There is strong evidence to suggest that the human aspect of the teacher-student relationship may promote deeper learning approaches and commitment on the part of the student. Ramsden condenses extant research into some general principles of effective teaching (Ramsden, 2003, pp. 93-99). When the general principles are investigated, they fall into one of four broad categories:

- The teacher's *attitude* towards teaching and towards students;
- The teacher's personal *attributes* (skills or gifts) that are used in their teaching and interaction with students;
- The teacher's *approach* to their teaching activities; and
- The teacher's *willingness to learn* from student reviews and feedback.

3.2.1 Teachers Attitudes

Ramsden (2003, pp. 72-77) describes some essential attitudes that teachers need to exhibit particularly if they are teaching adults. He talks of having respect for the student, developing a rapport with the student, and having reasonable expectations of student workload. He also discusses the personal commitment of the lecturer as being important in encouraging students to see content as relevant to the real world. According to Ramsden, teachers need to have a genuine interest in the students, and work at developing a climate of trust. This idea could also be considered as displaying generosity towards students. Ramsden (2003, p. 94) described teachers who showed genuine concern and respect for students and their learning as being mandatory but scarce commodities in higher education, especially in engineering.

Entwistle and Ramsden (1983, pp. 169-175) questioned students about the characteristics of their lecturers that helped to promote deep approaches to learning. The responses to their questions highlighted a number of personal qualities that are desirable in teachers in order to promote deeper learning tendencies in the students. In addition to those characteristics noted above (Ramsden, 2003, pp. 72-77), students noted that effective teachers were willing to help students with their learning when required, and were enthusiastic in their work.

Knowles (1990) also contributes to the list of attitudes desirable in an effective teacher of adults. He repeats Entwistle and Ramsden's observation that teachers need to be genuine in their dealings with students and show students trust and respect. Additionally, Knowles describes the need for empathy when dealing with students, being supportive of students' efforts, and an enthusiastic individual.

Entwistle and Ramsden (1983, pp. 169-175) also provide some insight into the main characteristics that students did not like in teachers' attitudes towards teaching and students. Students indicated that teachers who appeared not to like students, nor to have any real interest in the students, tended to detract from the students' learning experience.

3.2.2 Attributes of Teachers

Ramsden (2003, pp. 72-77) describes how effective teachers must be able to explain things clearly to their students. An ability to make material genuinely interesting and provide clear explanations is critical to promoting learning in all students. The section on *student approaches to learning* indicated that interest, relevance and practical application of the material being studied were attributes associated with promotion of deeper learning approaches.

The ability to make complex subjects more easily understood and less frightening to the student is an important attribute of an effective teacher but one that often requires great levels of technical mastery and effort. One of the main symptoms of an inability or unwillingness on behalf of lecturers to explain things to students is that subjects appear much more demanding than they actually are (Ramsden, 2003). In contrast, teachers who are able to make complex subjects easier to understand minimise student's anxiety and cynicism about subjects, enhancing the learning experience (Biggs, 1991, pp. 21-26). Tobin and Fraser (1988) found that a common characteristic of excellent teachers was that they were sensitive to student misunderstandings and were willing to employ a variety of teaching strategies to help students understand.

Albert Einstein recognised the importance of explaining complexity at a student's level and provided the following advice to teachers (Howe, 2006, p. 105):

> *"If you can't explain it simply, you don't understand it well enough."*

Ramsden is not advocating trivialising complex material by overly simplifying it. He still considers controlled intellectual challenge as being important as long as it can be made interesting and exciting to students (2003, pp 96-97). Biggs (1991, p. 20) reinforces this when he states that lecturers who keep students actively involved and challenged promote deeper learning approaches.

Ramsden (2003, p. 160) recognises the need for effective teachers to be good at listening, as well as talking, when he describes teaching as a conversation, where listening and talking are equally important. The ability to listen accurately to students therefore becomes another attribute of effective teachers.

3.2.3 Approaches to Teaching

Teachers must also work to create an appropriate learning environment to encourage deeper learning in their students. This environment is described as being *warm* by Biggs (1991, pp. 21-26). Knowles describes this warmth as relating to both the physical and figurative learning environments. The physical environment needs to be comfortable (including ventilation, temperature, lighting and so on). The humanistic environment also needs to be suitable and include an atmosphere of mutual trust and respect, helpfulness, freedom of expression, and one that promotes an acceptance of differences (Knowles, 1990, p. 85).

As well as having technical mastery over a topic, effective teachers are able to teach at an appropriate level, which is determined by the students' level. These teachers are also able to teach at an appropriate rate, using examples and analogies to assist student learning, and using clear and concise style and tone. Effective teachers are willing to provide feedback to students on their performance and progress (Entwistle and Ramsden, 1983, pp. 169-175), and tend to focus on students' understanding of key concepts rather than the need to cover excessive amounts of material (Ramsden, 2003, p. 87).

The need to align teaching style with likely learning style diversity within groups of students was discussed in Chapter 2. If this teaching style alignment is done well, the resultant teaching styles should be accommodating of most, if not all, of the students in a class (Felder and Silverman, 1988). Felder and Silverman (1988) have developed a teaching style that aligns with each dimension of their LSI. These styles and the corresponding learning styles are described below:

- The ways students perceive information helps to determine the nature of the course content and, in particular, whether that content should be dominated by concrete facts or more abstract principles.

- The learning style associated with how students input information helps to determine how the information should be presented. Presentations may range from visual presentations to verbal presentations.
- The learning style associated with organisation of the information requires teachers to consider how best to organise the material.
- The way in which the students process information determines how best to manage student participation.
- The way in which students understand the material determines the perspective that teachers should place on the material.

Sternberg (1999) also supports the idea of teachers being more aware and accommodating of diverse learning styles through the use of a variety of teaching styles and strategies. Sternberg (1999) cites examples of accommodating teaching styles which include:

- Course content containing an appropriate mix of concrete facts, data, and phenomena as well as abstract concepts, theories and principles is likely to reach both sensors and intuitors.
- Presentations that include written and spoken words, along with visual tools accommodate both visual and verbal learners. Visual tools might include pictures and diagrams, but also flow diagrams in lieu of descriptions of complex processes, and graphs in lieu of mathematical functions. Live demonstrations coupled with verbal explanations may also reach both visual and verbal learners.
- Course structures that allow some inductive processing (by starting with concepts and inducing facts from these concepts) and some deductive processing (by working from facts and deducing concepts) engage both deductive and inductive learners.
- Avoiding long lectures that require a lot of note taking by the students. Long periods of note taking do not suit either active learners or passive learners because active learners do not enjoy passive activities such as note taking, and passive learners do not enjoy experiences that do not allow them opportunities to consider and reflect.
- Courses involving some group work (small groups are likely to work for both active and passive learners), class discussions, and question/answer sessions, and a mix of both practical and theoretical content are likely to engage both active and passive learners.

- Courses that have clear structure and content are critical in facilitating both sequential and global learners. Sequential learners enjoy courses that progress in a logical and sequential fashion whereas global learners are more likely to focus on the bigger picture before smaller details and concepts. Providing motivation by demonstrating how the course is building on previous material and situating the students for future learning also appeals to inductive and global learners.

Students were also able to provide Entwistle and Ramsden (1983) with some insight into the main negatives associated with teachers' approaches to courses. They described inappropriate assessment methods and excessive workloads as being problematic. Both of these factors were also discussed in the section on student approaches to learning as promoting the undesirable surface approach to learning.

3.2.4 Using Student Feedback

Ramsden (2003, pp. 86-87) describes good teaching practice as involving a willingness to learn from students (especially from student feedback and from their assessment results) as a way of improving teaching; and he cites research that indicates students are very astute judges of effective teaching, making their reviews particularly informative. He describes the research as undermining the popular view, from those lecturers who receive poor student reviews, that students confuse popular lecturers with good lecturers. Marsh (1987) also agrees with this point by describing properly collected student ratings as reliable and valid, and relatively free from contamination by the many variables often viewed as sources of potential bias. Some of the variables that are incorrectly associated with biased student reviews include (Webb, 1994, pp. 43-46):

- Student variables such as age, sex, personality and academic performance;
- Teacher variables such as popularity, personality, lenience, sex, age, teaching experience, and research output; and
- Course variables such as simplicity and entertainment value.

The case studies presented in Chapters 5, 6, and 7 relate to work done at UNSW. UNSW is an example of a university that regularly seeks student feedback on its courses and teachers. In outlining their process for teaching and course improvement, UNSW (2007) states that there is general agreement across the relevant scholarly research that students can provide valid observations and judgments on a range of aspects of teaching quality. Accordingly, UNSW has designed and developed a review process aimed at accurately capturing student comments in order to improve teaching and learning quality within the university.

Brookfield (1995, pp. 28-48) extends the idea of listening to student reviews when he describes his *four critically reflective lenses*. The lenses are metaphors used by Brookfield to illustrate that teachers wanting to improve need to see things through not only their own eyes (one of the *lenses*) but also through their colleagues' eyes, the 'eyes' of literature and research, and through their students' eyes. Student reviews, comments, and criticisms form part of that fourth *critically reflective lens*.

3.3 Conclusions

This chapter investigated the impact teachers have on adult learning. The role of the teacher as a learning facilitator was investigated as being particularly important in adult education. As a facilitator, the teacher needs to enable learning by assisting students with the interpretation, understanding, and comprehension of information and problems. This is described as a student-centred approach.

Technical mastery and an ability to communicate were considered to be critical attributes of effective teachers of adults. The willingness to listen to adult students was also described as an important attribute. Other desirable teacher attitudes that were discussed included a need to have a genuine interest in the students and in teaching, an empathy towards the students, and an enthusiasm for the topic. Apart from attitudes and attributes, teachers of adults also need to be aware of likely learning style diversity in groups of adult learners, and be willing to adopt a variety of teaching approaches in order to cater for this diversity.

The chapter concluded by describing the need for teachers to be willing to listen and learn from their students in order to improve their teaching. Examples of valid forms of learning from students included reading student reviews of their teaching and observing student assessment results.

Chapter 4

A Conceptual Framework for the Design, Development and Delivery of Courses for Adult Learners

4.1 Introduction

The literature review documented in Chapters 2 and 3 has detailed aspects of the current scholarship of teaching and learning (SOTL) relating to adult learners and the teachers of adults. Each of these aspects provides important guidance for the design and development of educational activities. The main points from the literature review relating to course design and delivery are:

- **Andragogy**. Adult education tends to be centred on the learner and the learner needs to understand why the educational experience is important. Each learner will have their own ideas about the need to learn and will be motivated accordingly. Course design should provide learners with a meaningful and motivating context that ensures learners appreciate the need to learn.
- **Experience**. Adult learners come to the learning activity with considerable experience. There may be considerable variation in experience across a group of adult learners, which puts individual learners in different 'starting' positions. Each learners' experience should be appreciated and allowed for in the course design process to ensure that the level of the course is appropriate. The learners' experience should also be considered an important learning resource and used where appropriate throughout the delivery of the course.
- **Learning Styles**. Each learner will have different learning style preferences with regard to how they acquire, process and assimilate knowledge. Although

the 'average' learning style preference of the group may be determined, learning style preference is an individual preference not a group preference. It is unlikely that a single teaching style will suit all learners. Therefore, allowances should be made to cater for variation in learning style across the group when developing the course, the learning resources, and the teaching strategies.

- **Approach to Learning**. Each student will adopt a particular approach to the learning activity, often in response to the design of the course and its assessment. In complex and structured courses, a deep approach to learning should be encouraged as this results in more thorough and long lasting learning.
- **Approach to Teaching.** Authors have warned teachers against using excessive amounts of material and overloading students with a high workload. Instead, to promote deeper learning, they recommend the creation of an active learning environment that offers some choice to the student, with well-structured courses and assessments.

These principles should inform the design, development and delivery of educational activities and the learning resources and materials used to support those activities.

Chapter 3 detailed what current research says about the attitudes, attributes and approaches of effective teachers of adults. This information should inform how the educational activity is delivered. The literature review indicated that, from a learner perspective, the teacher or learning facilitator may have a major bearing on the quality of the educational experience as far as the learner is concerned.

4.2 Concept and Overview

This chapter describes a conceptual framework that was developed from these principles that can be applied to the design, development, and delivery of technical courses to diverse groups of adult learners. The context of this chapter of the dissertation in relation to the literature review is illustrated in Figure 4-1.

As shown in Figure 4-1, the design, development and delivery of educational material must be done with both the student and the teacher in mind. Note that the term *material* in Figure 4-1 has been retained as it comes directly from Entwistle and Ramsden (1983, p. 2) but it is used here to include course structure, content, assessment, supporting material and so on.

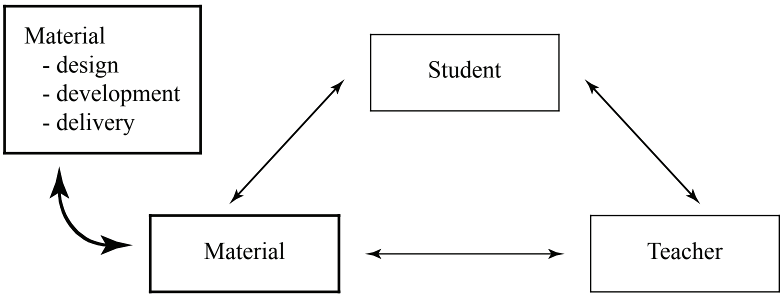

Figure 4-1. Design and development of the course material.

It is not the intention of this chapter to provide a set of instructions relating to the detailed process of design and development of educational course structures and learning resources. These detailed instructions are well documented in existing handbooks, texts, and guides. Examples include those written by Newble and Cannon (1995) and Caffarella (2002). Additionally, the detailed process is also often institutionally mandated by university policy and procedures that form part of a broader academic quality assurance system. Instead, this chapter concentrates on the development of a conceptual framework within which courses can be designed, developed and delivered, and highlights some of the key considerations that make it suitable for adult education.

The framework can be used to develop a *learning superstructure* for adult learners who are learning about complex, technical topics. The *learning superstructure* is described by Biggs (1991, p. 17) as being formed by the structure of a course, the content of the course, the teaching method employed and the assessment models used, and therefore relates to *material* in Figure 4-1. Biggs goes on to describe the superstructure as critical to the learning process and its formation has important student motivational consequences. The need to gather information continually on the effectiveness of the superstructure is also critical to its ongoing improvement (Ramsden, 2003, p. 120).

Biggs's concept of a learning superstructure could be considered a *system* whose purpose is to promote learning because a system is defined as *a complex set of parts that come together to serve a common purpose* (Faulconbridge and Ryan, 2005). Education can be considered a *system* at any one of a number of levels (Biggs, 1991, pp. 221-228) including at the individual course level. Therefore, a learning system (as defined by Biggs and his learning superstructure) can be thought of as a complex integration of course structure and content, assessment methods, and teaching methods delivered in such a way as to facilitate the desired learning in a group of students. The development framework presented in this chapter builds on the concept of education as a *system*, and applies established *systems thinking* to the design, development and delivery of effective educational systems.

The framework has been found to be sufficiently adaptable and flexible to account for the many variables encountered during the design, development and delivery of adult education. Some key variables that may be encountered during the design, development and delivery of adult education include:

- the nature of the topic to be taught, which may range from very detailed and focused technical topics through to more general topics;
- student age, and the age variations within the group, which may contribute to learning style diversity within the group;
- relevant student experience levels within the group, which place individual students at different positions between the novice and expert ends on the continuum, illustrated in Figure 2-6, and may present opportunities to use student experiences as a learning resource;
- future employment of the students which helps determine the educational need and the learning context of the educational experience;
- the range of educational backgrounds and academic capabilities of the students, which may help to determine the level of the course, the teaching strategies adopted, and may limit the learning approaches adopted by the students;
- the aims of the education, ranging from undergraduate education to more vocationally-focused professional development; and
- the nature of the constraints placed on the course, including timing constraints, availability of training aids to assist with delivery, and institutional requirements for assessment.

The application examples that follow this chapter in Chapters 5, 6, and 7 demonstrate the application of the framework to three learning situations where there is considerable variation in the educational variables listed in the previous paragraph. By illustrating the application of the framework to three different educational situations, the framework's flexibility and adaptability is explored.

This chapter first introduces the essential elements of a development framework and then integrates those elements to illustrate how the framework can be used to develop learning superstructures or systems. The essential elements of the framework discussed are:

- a lifecycle model for learning development,
- a means of appreciating the need driving the design of the activity, and
- a development methodology to develop the learning superstructure or system from the need.

4.3 A Suitable Lifecycle Model

4.3.1 Introduction

Lifecycle models are traditionally used to break complex problems down into manageable and logical sequences of stages; each stage building on the preceding stage. A key feature of lifecycle models is that the current activity is performed with future activities in mind. In the design and development of educational activities, this means that the design and development takes place whilst keeping the student, the ultimate delivery, and the desired outcomes of the course in mind. Therefore, a suitable lifecycle model is the first element of the conceptual framework.

A number of project management standards and engineering standards describe generic lifecycle models to facilitate the breakdown and management of complex projects (PMI, 1996), (EIA-632, 1999), (DoD-STD-2167A, 1985). These standards are generally tailored by individual organisations or industries to develop specific lifecycle models that ideally match organisational imperatives.

All lifecycle models start with the identification of some need or problem, followed by a sequence of stages and activities that together bring a system (or solution) into existence. The system is then used to solve the problem or address the need. Most lifecycle models also recognise that systems may need to be changed, or modified, throughout their lives before the system is ultimately disposed of when no longer required.

An example of an educational lifecycle model is shown in Figure 4-2. This model was proposed by Houle (1972, p. 47) and contains a number of decision points and activities arranged in a logical fashion. The lifecycle starts with the identification of an educational need and finishes with the system being put into practice and measured. Importantly, Houle’s model also recognises that educational ‘systems’ need to be continually measured and modified throughout their lives, as shown by the feedback loop in the model.

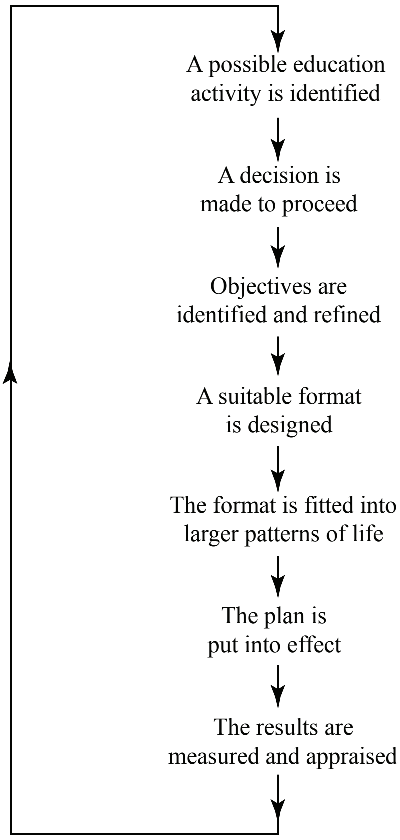

Figure 4-2. Houle's educational design lifecycle.

Houle's model is designed to support a wide range of educational design activities ranging from individual teachers designing activities for themselves through to the design of a new educational institution.

The framework being developed in this section is designed to support the development of educational activities to be delivered by a single teacher (or small group of teachers) for groups of adult learners. A simplified lifecycle model has been used for this purpose.

An Australian/New Zealand standard (which is derived from an established international standard) summarises and consolidates existing lifecycle models into a tailorable lifecycle model that can be used to support very complex or quite simplified projects (AS/NZS15288:2003, 2003). Using Houle's model as a basis and the guidance contained in AS/NZS15288, a simplified lifecycle model to support the development of educational activities for groups of adult students is shown below in Figure 4-3. It is shown flowing from left to right (rather than top to bottom) to support its integration with the broader development framework used later in the section.

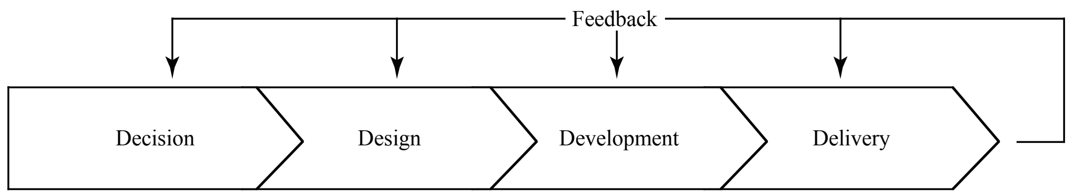

Figure 4-3. Simplified educational design lifecycle.

From left to right, Figure 4-3 shows four broad stages (four "Ds") in the development of educational activities and incorporates a mechanism for feedback and improvement:

- **Decision**. During this stage, the need for an educational activity is identified and the decision is taken to start designing and developing an activity to satisfy the need. The broad aims and objectives of the activity are identified in order to define what the student needs to learn and why they need to learn it (Ramsden, 2003, p. 125).
- **Design**. In accordance with Houle's framework, design involves identifying and refining the detailed aims and learning objectives. Design also involves determining how the course will be structured, the inter-relationships within the structure, and the assessment methods to be employed. This stage determines the detailed requirements for the learning resources and materials that will be required to support the activity.
- **Development**. As the name suggests, this is the stage during which the learning resources and materials are either identified and sourced (if they exist) or developed in accordance with the course design determined in the design stage. As delivery is the next stage in the model, the learning resources and course material that may need to be developed include all of the necessary resources that do not currently exist. Notes, lecture packs, readings, texts, experiments and assessments need to be prepared during this stage.
- **Delivery**. This is the stage during which the activity is executed or performed. The students experience the learning activity, make use of the resources developed in the preceding stage and are assessed in accordance with the assessment plans and materials. Appraisals and assessment of the activity by the lecturer and the student also occur during this stage.
- **Feedback Loop**. As shown by the feedback in Figure 4-3, appraisals may drive the requirement to re-design or re-develop aspects of the activity. Changes may also be needed to the delivery of the activity to improve how it was received. The importance of student reviews following delivery was described in Section 3.2.4. Of course, in some cases, activity appraisals may cause a reassessment of the decision to run the activity in the future.

4.3.2 The Decision Stage

The first stage in the lifecycle model is the decision to develop an educational activity based on an educational need. As shown in Figure 4-4, the visualisation of the need for an educational activity can be assisted by the continuum concept introduced in Section 2.2.2.

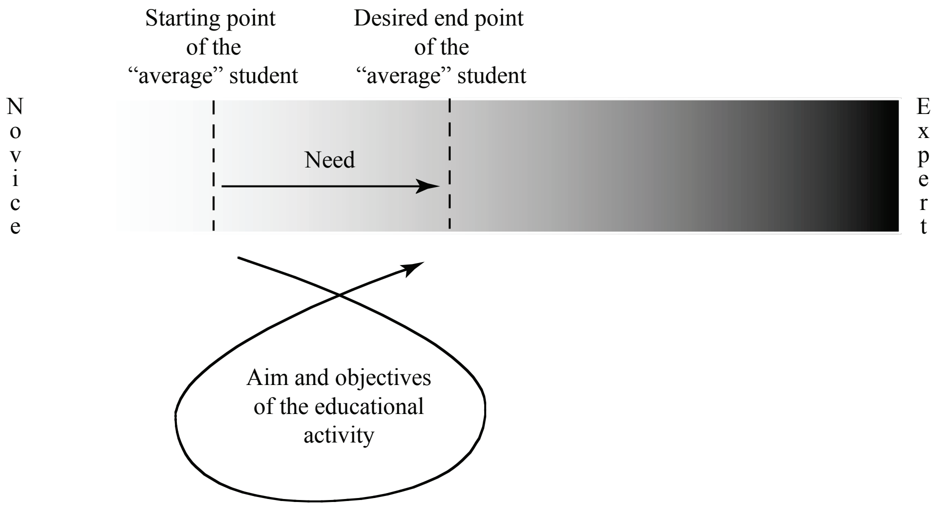

Figure 4-4. The continuum illustrating educational need.

The need, as illustrated, accounts for both the level of experience that the 'average' learner possesses at the start of the educational experience and the desired amount of change. The need for education may come from a range of sources including industry requirements for certain skills and knowledge, or groups of students seeking particular educational experience. The desired change to the learner in terms of cognitive skills, knowledge and attitudes defines the need for the activity. The literature review discussed a unifying perspective that education is about effecting change in students. Accordingly, when defined, the need should explain what change to the students is expected as a result of the proposed education. It is upon this need that the design and development effort is based when using a top-down, systems approach to development. The need can be initially defined and documented in terms of a learning aim and broad objectives for the activity.

From a learning perspective, establishing a credible need for the educational activity is critical in adult education as explained by the literature on the andragogical model of education. Adults have a motivation to learn based on the ability of the educational activity to serve some purpose such as to explain something meaningful to them. By carefully considering the need for the education and expressing the need in practical and relevant terms, the adult learner will be more likely to understand the need for the education. The literature review discussed the importance of getting the adult learner to commit to the educational activity to promote deeper learning approaches. Designing educational activities that are practical and relevant to the adult learner will assist in fuelling their motivation to learn.

The need and desired outcomes are therefore at the top of a virtual *pyramid* under which will sit the structure and content of the activity. The concept of the pyramid is illustrated in Figure 4-5.

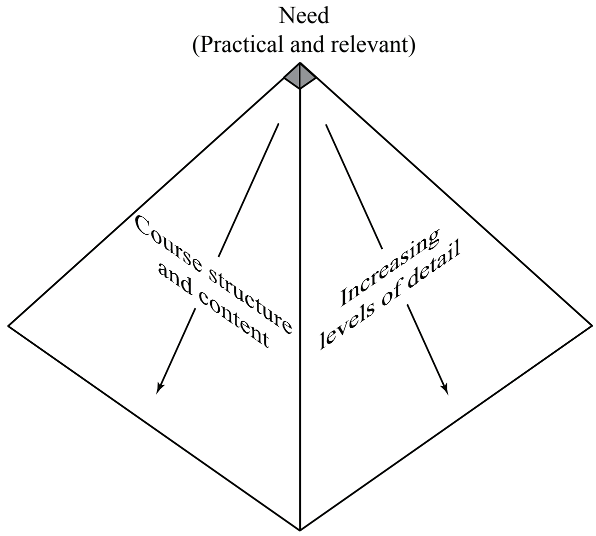

Figure 4-5. Pyramid peaked by the need.

The need should be clearly stated in order to support verification and validation of the educational activity once it has been delivered to the target group of students. From a design perspective, the stated aim and objectives (need) of the educational activity determines the more detailed learning objectives that serve as the ultimate test of suitability. The aims are general statements of educational intent, where as the learning outcomes and objectives are more specific and concrete (Ramsden, 2003, p. 126), and therefore measurable. To assist in drafting learning objectives and then learning outcomes, the US Department of Defense (MIL-HDBK-29612-2A, 2001) talks about Knowledge, Skills, and Attitudes (KSA) and provides a comprehensive list of verbs to help course designers to articulate the learning objectives in these categories. Other texts that focus on course design also provided similar lists of verbs (or ‘action words’) that can be used when determining and articulating the learning outcomes (Caffarella, 2002, p. 171).

Dependencies and constraints associated with the design and development of the activity should be documented along with the need. Examples of dependencies and constraints in an educational context may include the following.

- The range of experience and expertise of the students entering the activity. The literature review discussed the important role that student experience plays in the education of adults.

- The presence of students from different language, cultural, or educational backgrounds.
- Time and resource constraints associated with the activity. Again the literature on student approaches to learning clearly shows that creating time pressures with excessive amounts of course material promotes a surface approach to learning.
- Organisational guidance on content, instructional techniques and tools to be used in order to maintain consistency across a curriculum.

Once the aim and broad objectives have been established and the constraints identified and understood, the decision to proceed with the design can be made. The role of the framework focuses on devising a course structure that is sufficient to satisfy the need. In this way, the need is always driving the design of the learning activity (Faulconbridge, 2003) and can be referred to during delivery to reinforce the relevance of the material being learnt.

4.3.3 The Design Stage

The next stage in the lifecycle model is the design process required to translate the educational need into delivered and verified learning outcomes. The aim and broad objectives of the educational activity form the foundation of the design process. The design process uses the broad aims of the course to derive learning objectives and detailed learning outcomes. In order to promote student adoption of deeper learning approaches, designers must develop a meaningful structure of aims, objectives and outcomes, with appropriate breadth and depth, and linkages. A logical framework is an attribute of course design that students report as being important to them (Ramsden, 2003, p. 122-123). This means that the structure should be meaningful from the perspective of the students and should be used to put the learning aims, objectives and outcomes into context for the students. The students could think of this structure as the *knowledge structure* for a given course. Because the knowledge structure is meaningful to the students (based on their experience and background), it not only explains what is going to be learned but also why it is important. A mindmap[1] is a useful construct to illustrate the knowledge hierarchy expressed as aims, objectives and learning outcomes; and an example is shown in Figure 4-6.

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[1] Mind mapping software called NovaMind has been used for this work. Copies of the NovaMind software can be obtained online from http://www.nova-mind.com.

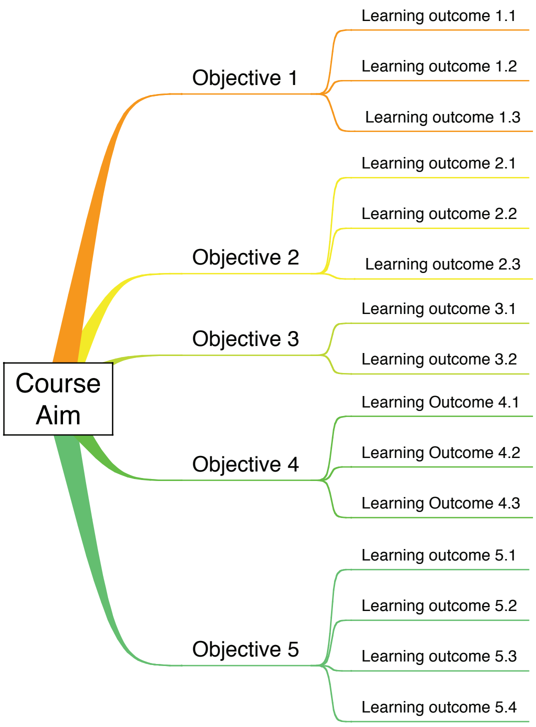

Figure 4-6. Knowledge hierarchy (conceptual)

Once the knowledge structure has been determined, designers must decide on the structure of the course that will be used to deliver the learning outcomes. A clear relationship is needed between the learning outcomes as expressed in the knowledge structure and the course structure that is designed to deliver those outcomes. The structure of the course helps determine the detailed course content requirements and the necessary teaching resources. There are many sources of information to assist designers in determining detailed course structure and content, for example (Ramsden, 2003, p. 130-131) lists these as including:

- requirements from relevant professional bodies;
- similar courses and examinations from other institutions or organisations;
- discussions with colleagues, practitioners, and employers;
- discussions with students;
- relevant research relating to education in the field;
- classic or well-established texts in the field; and
- the relative position of the topic in the overall curriculum or program of study.

The relationship between the knowledge structure and the course structure can be illustrated by a series of links between the knowledge structure and course structure as shown in Figure 4-7.

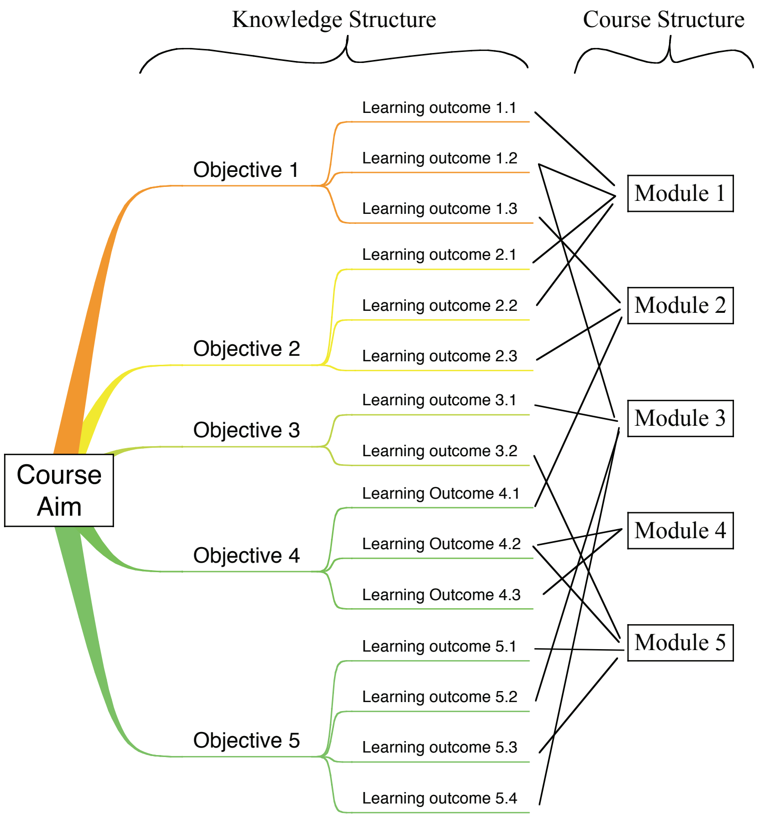

Figure 4-7. Knowledge structure and course structure relationship (conceptual)

This method of showing the relationship between knowledge structure and course structure quickly becomes unworkable in a situation involving many learning objectives and detailed course structures. It is used in this chapter for illustration purposes.

A more practical approach to identifying the linkages, called an allocation matrix, is used in Chapters 5, 6, and 7. A conceptual allocation matrix, showing the same information as Figure 4-7, is illustrated in Figure 4-8. The allocation matrix quickly confirms that:

- the knowledge structure is being covered by the course by showing that all learning outcomes in the knowledge structure have been allocated to at least one module in the course structure; and
- the course structure does not contain unnecessary material by showing that all modules in the course structure are contributing to at least one learning outcome in the knowledge structure.

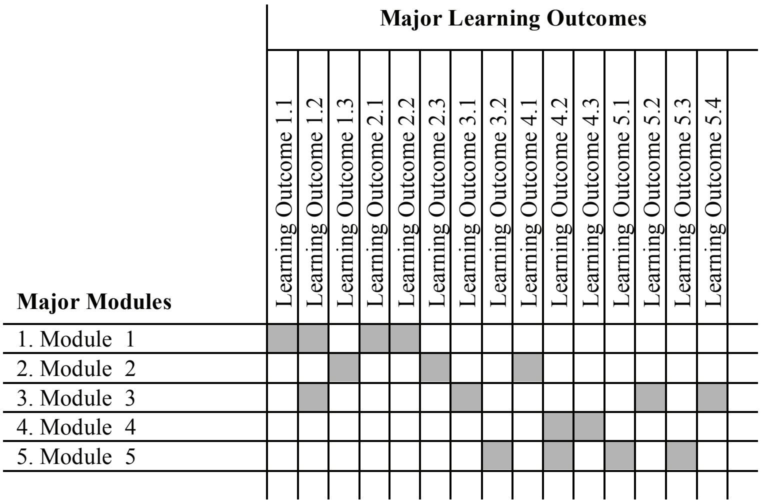

Figure 4-8. Allocation matrix (conceptual)

Once the course structure is defined and the learning outcomes allocated, the designer can then identify possible learning resources and approaches that are best suited to achieving the learning outcomes assigned to each module. A non-exhaustive list of examples of learning resources and approaches include the use of lectures, group discussions, self-directed learning, private reading of textbooks, assignments, multimedia, field trips, and laboratory experiments. This concept is illustrated in Figure 4-9.

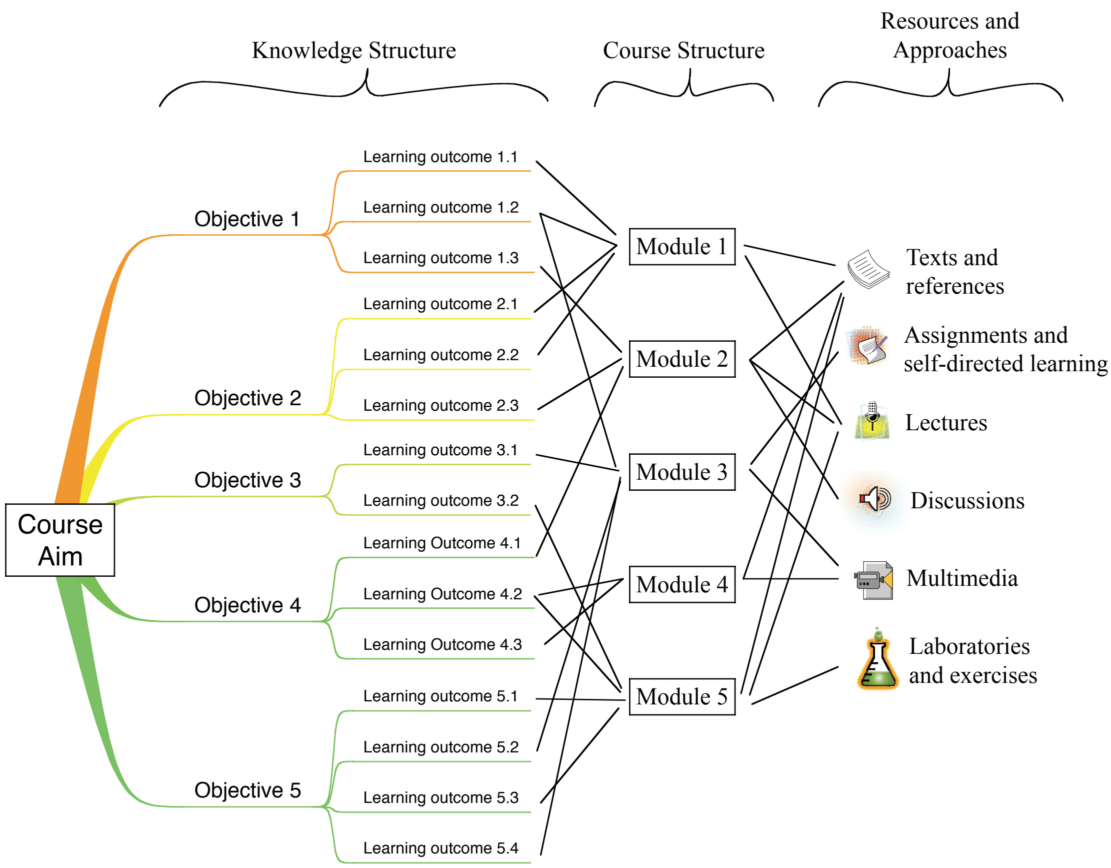

Figure 4-9. Determining the learning resources and approaches (conceptual)

The course designers are able to view Figure 4-9 from right to left to appreciate the detailed requirements for each learning resource. For example, in Figure 4-9 the designers need to develop a laboratory exercise as part of module 5, which in turn is delivering learning outcomes 3.2, 4.2, 5.1, and 5.3. This process leads to the *development* stage of the lifecycle that is covered in 4.3.4.

4.3.3.1 'Top Down' and 'Bottom Up'

Starting with the aim, and then progressively deriving additional levels of detail in the form of objectives and learning outcomes, and finally determining the most suitable resources and approaches to achieve the learning outcomes is an example of what is known as *top-down design and development*. Top-down design and development is a well-established technique used to solve complex technical problems. The concept of top-down design was pioneered by the large and complex projects of the United States Department of Defense in the 1950s and 1960s. The top-down approach to complex problem solving has been progressively refined and is well documented in a range of United States Department of Defense engineering standards starting with MIL-STD-499B (1994) and commercial engineering standards such as EIA/IS-632 (1994), EIA-632 (1999), and IEEE-1220 (2005), and the pioneering software development standard DoD-STD-2167A (1985).

The main benefit of top-down design is that the need drives the detailed design of the activity. The resultant design therefore stands a good chance of satisfying the original need without exceeding it. This contrasts with a bottom-up approach where existing courses and material are employed in an attempt to satisfy an educational need. An example of bottom-up design is the selection and use of an existing resource such as a textbook as the main teaching resource for a given educational activity. The text may be selected based on its ability to cover the necessary material in a suitable format, but it is unlikely that the text will have been written specifically with the educational need in mind. To that end, the use of existing course materials and resources is unlikely to address the need ideally. There may be a gap in the selected resources requiring the lecturers to address the gap left by the bottom-up approach to course design. It may also be possible that the existing material is unsuitable in some other way such as inappropriate level of detail, or excessive information. The bottom up approach may also result in the original educational need being slightly adjusted to align with the resources. This may put the validity and creditability of the need in question.

In reality, it is likely that a mix of top-down and bottom-up design occurs, but the educational need must remain the driver of the process and should not be compromised by bottom-up design.

A top-down design and development process that was pioneered by Forsberg and Mooz (1991) is called the 'VEE' diagram or process. Since its establishment in 1990, the "VEE" process has become one of the foundation process models in the systems engineering discipline (Blanchard and Fabrycky, 2006) used to solve large and complex technical problems in a methodical fashion. Section 4.2 discussed the concept of educational activities being considered *systems* on a number of levels. If the design and development of educational systems is considered a complex problem, the 'VEE' construct illustrated in Figure 4-10 may be applied.

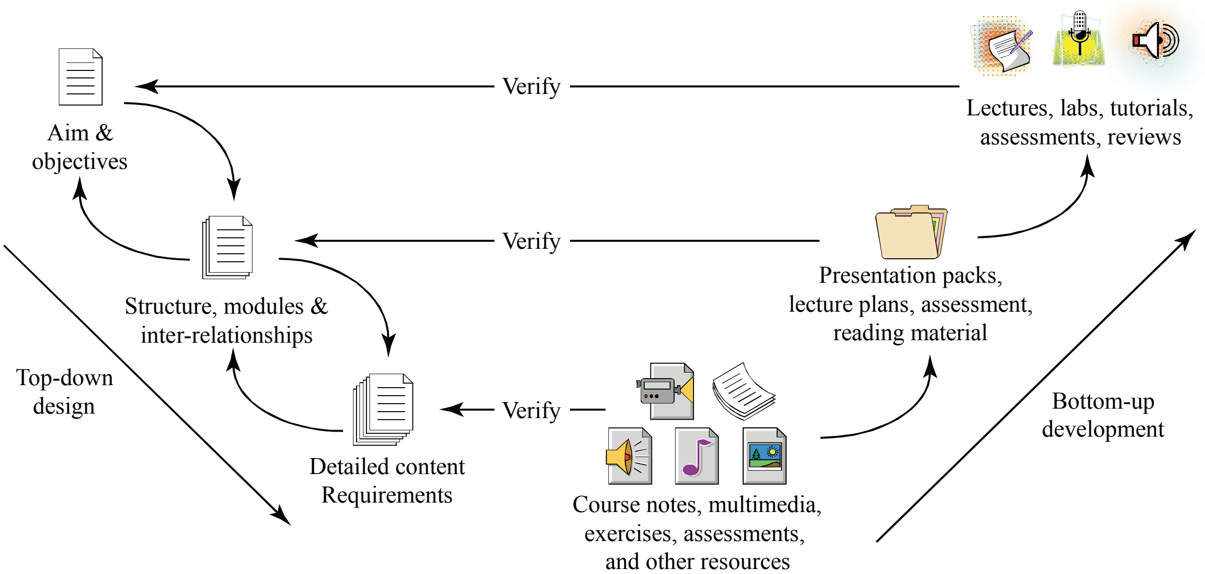

Figure 4-10. VEE diagram applied to educational development

The VEE diagram is designed to be viewed from the top left, down to the 'bottom of the VEE' and then back up to the top right. On the left hand side of the VEE is the design of the activity, consisting of need, structure, and content requirements (as discussed in this section using a series of mind maps). On the right hand side of the VEE is the development activity including the development of the detailed content, selection of existing educational material and resources, and ultimately the delivery of the education. Development and delivery are discussed in the next sections.

There are some key attributes of a typical top-down approach to design that make it particularly relevant to the design and development of educational activities, especially when considering the content of the literature review. The key concepts are:

- traceability of course content back to the defined aims and learning outcomes;
- identification and definition of the inter-relationship between modules and content;
- progressive verification as the development proceeds; and

- the 'Assessability' of learning outcomes and objectives.

4.3.3.2 Traceability

The relationship between the need, learning objectives and outcomes, and the course structure and content is called *traceability*. Traceability needs to exist in both directions; forward (from need → outcomes → learning objectives → course modules → learning resources and approaches) and backwards (learning resources and approaches → course modules → learning objectives → outcomes → need).

Forward traceability provides confidence that the entire educational need has been considered and addressed by the proposed course structure. Forward traceability must exist throughout the entire design process so that it is always possible to demonstrate that each of the elements of the need is being addressed by the course structure and content. Forward traceability will highlight any objectives or learning outcomes that are not being addressed by the course structure.

Backward traceability exists in the reverse direction, and shows why a given module or learning resource is critical to the satisfaction of a given learning outcome. This traceability is a powerful tool in demonstrating the relevance and importance of course detail to adult learners whose motivation and approach to a learning situation may depend on a demonstration of this traceability. Backward traceability also protects course designs from unnecessary or excessive content by relating content requirements back to the satisfaction of learning outcomes or objectives. If it is found that there is no backward trace between an element of course content and the learning objectives for the course, then either the content is not required to achieve the learning outcome, and can be removed, or the learning outcomes need to be adjusted.

Being able to justify course content to students by its traceability to learning outcomes and educational need is useful during the delivery stage. Protecting the course and the students from excessive and irrelevant content also helps to guard against the inadvertent promotion of surface learning tendencies in the students (as discussed in the literature review) that can result from excessive workloads and course material. The allocation matrix, illustrated Figure 4-8, shows one way of illustrating traceability between the knowledge structure and the course structure.

4.3.3.3 Inter-relationships

In his description of the SOLO taxonomy, Biggs refers to the need to integrate knowledge into a structured form in order to move towards expertise (1989). The literature relating to deeper approaches to learning also emphasised the importance of structure and context as opposed to disjointed modules and facts. In a top-down approach to course design, the identification of relationships between elements of the design is of critical importance when it comes to successful integration. Accordingly, the interfaces, relationships or dependencies between the individual modules should be identified and accommodated when identifying educational modules and resources within the structure.

The identification of relationships, dependencies and interfaces between the modules impacts on the delivery of the course and on the ability to tailor or change the course during the delivery. Clearly, if there are dependencies between modules, the order in which they are presented can be critical. These dependencies are also critical when considering tailoring or omitting some course content during delivery. Interfaces and dependencies also help students to understand how the various components of course content relate to one another, promoting a deeper and more critical level of understanding.

4.3.3.4 Verification

Another key aspect of top-down design and development relevant to this framework is the importance of periodic verification. Verification in this context does not refer to assessment of students, but rather assessment of the design of the learning activity against its requirements. At the lowest levels (the bottom of the VEE), this requires detailed content to be checked against the requirements for the individual modules. Forward and backward traceability is confirmed during this verification process to ensure that the content is adequate. Once all of the detailed content has been checked, the next level of detail can be verified. This involves confirming that the modules that have resulted from the integration of the various components cover the module requirements. Finally, when the course is delivered to students, the upper level can be verified in the form of confirming that the intended learning outcomes, or objectives, have been achieved. This level of verification involves student reviews and the performance of the students in the various course assessments. If at any stage the verification fails, some redesign and redevelopment may be required.

The idea behind ongoing verification in top-down design is to identify problems with the course design as soon as possible. The earlier the problems are identified, the easier the rectification will tend to be.

4.3.3.5 Assessability

It is clear from the literature review that assessment methods have a major impact on students' learning experiences by influencing the approach they take to their learning tasks. For example, inappropriate assessment methods can foster surface approaches to learning

(Gibbs, 1992, pp. 8-11), as can threatening or anxiety-promoting assessment (Entwistle and Ramsden, 1983, p. 21), leading to a reduction in the quality of the learning outcomes.

Broad assessment strategies must be thought about at the same time as the educational need and learning outcomes are being written. The learning outcomes need to be written so that they are measurable and assessable. Considering assessment strategies at this early stage and writing assessable learning outcomes helps to ensure that assessment becomes an integrated part of the learning experience rather than an add-on. This approach helps to avoid the common perception that assessment is simply something that happens at discrete points through the session rather than being an integrated part of the learning journey (James et al., 2002). Ramsden provides some useful guidance on the design of effective assessment strategies stating that assessment needs to be linked to the learning objectives of the course and a variety of methods should be employed (2003, pp. 204-205). He also urges that assessment methods be selected that promote deeper learning by rewarding demonstrated understanding and punishing memorisation and imitation. He also suggests that where possible, assessment strategies should afford students some choice on how they are to be assessed.

Writing the detailed assessment tasks (in this conceptual framework) occurs during the development stage, and marking the assessments is part of the learning delivery stage.

4.3.4 The Development Stage

When the bottom of the left-hand side of the VEE is reached, development activities start. Course content and material need to be written, and learning resources need to be identified in order to enable delivery of the group of learning outcomes required of each module of the course. Newble and Cannon (1995, pp. 128-129) suggest some useful guiding principles that should be considered when developing educational materials, including:

- **Relevance and linkage**. The material should be relevant to the purpose for which it has been selected. In a top-down design and development process, the requirement for detailed educational material should be clearly traceable to the achievement of learning outcomes and linked to the other material in the course. If this traceability and linkage does not exist, some redesign is required.
- **Simplicity**. The material needs to be aimed at the appropriate level (as defined by the intended audience). This criterion requires avoiding the use of unnecessary complexity by making use of positive learning tools like drawings, diagrams and comprehendible explanations.

- **Emphasis**. Use of signs to stress important ideas, arguments or new material is also helpful. This includes the appropriate use of headings, text style, and colour in written material, and equivalent means of emphasising points in audio-visual material.
- **Consistency in pattern and style**. Maintaining a consistent style in educational material simplifies its assimilation by students. Newble and Cannon (1995, p. 129) state that this is one of the reasons why imported educational material may have less impact than material prepared by a local educator.

In addition to the principles discussed by Newble and Cannon, the likely diversity in student learning styles needs to be allowed for during the development of the educational material in order to support students who assimilate knowledge in different ways.

These guidelines can be applied to all of the learning material including written notes and texts, multimedia presentations, and use of instructional aids such as whiteboards, computer-based presentations, and overhead projections.

The principles can also be applied to the selection of critical learning resources such as course texts. The relevance, content, structure, and presentation of the text should be investigated by teachers in assessing the suitability of existing text books (Newble and Cannon, 1995, pp. 149-150). Apart from being relevant to the subject being taught, the content needs to be factually correct and current. The content also needs to be presented at the appropriate level as defined by the 'average' student's level of knowledge and experience. The continuum concept illustrated in Figure 4-4 can help here. The structure needs to be effective and should be compatible with the design of the course in terms of its chapters and sections. The presentation style used in the text also needs to be effective and make use of clear language, effective illustrations, and logical layout. It needs to be interesting as well, to promote its use.

Commonly observed problems with textbooks include (Ramsden, 2003, pp 153-154):

- texts containing excessive amounts of information and material creating workload issues and promoting a superficial (surface) approach to reading;
- the use of impersonal, dense and formal language that reduces the ease of use and utility of the resource;
- an unreasonable assumption about the reader's knowledge; and
- texts written without regard to facilitating deeper learning.

In situations where there are no texts in existence or where existing texts fail one or more of these criteria, the lecturer may need to consider developing their own notes or texts to support the educational activity. In these cases, the selection criteria discussed above provides guiding principles for the development of the notes or text.

In addition to the fundamental principles discussed above, Hartley (1985) provides comprehensive and detailed guidance for authors of course notes or texts. This guidance includes information on the planning of texts, formatting and writing, the role of illustrations and drawings, and the importance of content pages, indexes, and references. Additionally, if the texts are to be commercially published, the style guides of the publisher will further constrain the author. The application chapters that follow this chapter present educational development situations where technical texts were developed and published to support specific educational needs because suitable texts and resources did not exist.

Detailed assessments also need to be written during the development of the course material. This helps ensure that the assessment is aligned with the course material and forms an integrated part of the learning journey. Writing effective assessments tends to be difficult and time consuming, meaning that it is easier and less time consuming to write simplistic lower-level assessment that may only test surface learning (Ramsden, 2003, pp. 182-183).

Assessment should be included that is designed to provide students with constructive feedback on their progress, highlight their individual learning difficulties, and to identify areas needing improvement. This type of assessment, when not used to grade individual students, is called *formative assessment* and can provide important guidance to both the student and the teacher of a subject. In contrast, assessment that is designed to grade or rank individual students during or at the end of a given subject is called *summative assessment*. Both formative and summative assessment should be considered during the course development stage (OECD, 2005).

Ramsden (2003, pp. 204-205) provides 14 ‘rules’ relating to assessment that can be used to guide the development of course assessment.

1. Provide a link between assessment and learning by assessing during the learning process, not just at the end of the process. Where possible, consider setting problems based on real situations to reward students who are able to integrate and apply their learning.
2. When assessing, provide guidance to students on how they may improve their performance.
3. Be willing to learn from your students’ mistakes and misunderstandings discovered during the assessment process. This may allow the teacher to modify their teaching to address students’ difficulties.

4. Use a variety of assessment methods where possible rather than relying on a single method such as an exam to assess students' learning.
5. Promote active student participation in the assessment process by discussing assessment methods and their relationship with learning outcomes, allowing some negotiation of assessment methods, and offering some choice in assessment method.
6. Use the course goals, course delivery and the assessment tasks to reinforce continually that memorising facts, reproduction and imitation will not be rewarded, and that demonstrated understanding and learning will lead to greater levels of success in the course.
7. The relationship between assessment for reporting on student performance and assessment for providing feedback to the students on their progress should be justified on educational grounds. Do not blindly apply algorithms such as 'assessment used for feedback will not count for marks'.
8. Be very careful with the use of multiple choice and other objective tests. If they are to be used, use them in conjunction with other means of assessment.
9. In subjects involving quantitative manipulations, always include questions involving explanations as well as numerical examples.
10. Focus on the validity of the assessment ensuring that the assessment is measuring an understanding of the most important aspects of the course.
11. Try to reduce student anxiety raised by assessment.
12. Never set an assessment that you would not be ready to answer yourself. Always prepare model answers to the questions and use these to help students appreciate what was required.
13. Reduce between-student competition in assessments while providing inducements to succeed against a standard (such as an average).
14. Be suspicious of the objectivity and accuracy of all measures of student ability and recognise that human judgment is the most important element of every indicator of achievement.

4.3.5 The Delivery Stage

Chapter 2 provided guidance on promoting a deeper approach to learning in adult learners and considered the use of an andragogical (rather than pedagogical) model for adult learners. The idea of diversity in learning styles was discussed in Chapter 2 leading to a discussion on the need for diverse and accommodating teaching styles in Chapter 3. Chapter 3 also discussed the need for lecturers to play a facilitation role when dealing with adult learners and discussed the desirable attitudes, attributes, and approaches that adult educations should consider. This information informs the delivery of the educational activity that has been designed in accordance with the top-down approach described in previous sections.

Knowles (1990, pp. 85-87) provides a very useful set of guidelines describing the delivery of adult educational experiences. He describes the following conditions of learning and the associated principles of teaching:

- learners must understand the need for the learning experience;
- a suitable learning environment must be established;
- learners should 'own' the goals of the learning experience;
- learners should be responsible for the planning of the experience;
- teaching should make use of the learners experience; and
- learners should get a sense of progress towards the goals.

Biggs (1991, pp. 21-26) adds another element to this list, and that is the need to encourage integrated learning rather than promoting learning in discreet modules or pieces of course content. These and other principles are discussed in the following sections.

4.3.5.1 Ensuring the Learners Understand the Need to Learn

Courses and course material must be seen by the students to be practical and relevant. Students are generally strongly motivated by courses that they can see are relevant to their current studies or likely future career. Thinking that what they are learning now may help them succeed later is a strong motivator.

Convincing students that course content is practical and relevant is often difficult, especially if students are relatively inexperienced or relatively unaware in the subject domain, that is, closer to the *novice* end of the continuum. Inexperienced students may find it difficult to grasp context immediately without some assistance and may, in fact, not realise that the course content is practical and relevant. There are many tools available to the lecturer to help students understand the relevance of the course material. A non-exhaustive list of classic examples includes the following:

- Videos and multimedia. Appropriately selected and applied multimedia appeals to a diverse range of learning styles and can help to emphasise relevance.
- Guest lecturers. The literature review highlighted that students see experience and expertise in the lecturer as an important teacher attribute. Guest lecturers who are significant role models for the students or who have specific relevant expertise can be used to reinforce the importance of their study. Guest lecturers

need to be aware of the detailed structure and content of the course so that their presentation aligns with the course and reinforces the course content.

- Future employment. Adult students are motivated by courses that have a demonstrated link to their future employment (Miller, 1964, pp. 11-12). Searching the current job market using, for example, the Internet and newspapers for employment relating to the students' future qualification can highlight the knowledge and skills that they require to succeed professionally. A class exercise can involve discussing the job ads and extracting the essential and desirable characteristics and knowledge being sought by their employers. Developing some of these characteristics and providing some of this knowledge can be related to the course content particularly if relevant workplace competencies have been investigated when developing course learning objectives (Brumm et al., 2006).
- Real-life examples. Where possible, real-life examples should be used to highlight that the course material is, in fact, practical and relevant. Rather than fabricating theoretical worked examples and exercises, real systems and problems should be considered. Real-life situations can also be used as the basis of some assessment in what has been called 'authentic assessment' (Palmer, 2004). Authentic assessment attempts to relate student learning and assessment to the competencies, skills and knowledge required in professional practice.

Finally, students should be encouraged to reflect continually on the reasons why the course material is being covered. The linkages between course material and the peak of the pyramid that was defined during the design and development stage of the lifecycle need to be reinforced and revisited often during delivery. A mind map approach can be useful.

4.3.5.2 Establishing a Suitable Learning Environment

The literature review discussed the need to establish a suitable learning environment. This involved not only the physical environment (such as lighting, ventilation, and surrounds) but also the 'warmth' of the environment as established by the lecturer's attitude and approach to teaching. The literature review cited research that showed an environment that allows the learners to be active and to be 'learning by doing' promotes deeper learning tendencies. Interaction within the learning environments between students, the lecturer, and experts in the relevant field also assists in developing deeper learning philosophies.

By recognising that the learning environment extends beyond physical considerations, it may be possible to explore how these principles apply to online and distance education course deliveries in addition to traditional (face-to-face) modes of delivery. Online and distance education course deliveries are discussed in more detail in Section 9.6.

4.3.5.3 Discussing the Concept of Learning

Spending some time up front to explore the concept of learning with students before they embark on a particular learning experience may assist individual students to set their own personal learning strategies. This might be considered an adoption of part teacher/part counselor roles as defined by Biggs and explored in Section 2.3.5. Spending this time with the students may allow them to become meta-learners by being conscious of their options with respect to approach (deep versus surface). It may also be an opportunity to help students understand their learning styles with a view to understanding their own strengths and weaknesses (Felder and Spurlin, 2005). Conducting some form of learning style evaluation, as described in Section 2.4.3.1, may be useful in informing these discussions.

4.3.5.4 Giving the Learners Responsibility for Planning the Experience

Communicating the structure of the course to students is traditionally done at the start of a lecture series with the lecturer using a table of contents listing the topics to be covered in the course. Rather than *pushing* a course structure onto students, it is possible to *pull* the knowledge structure from the students and show how this knowledge structure relates to the course structure. This way, the course can be tailored to meet the individual interests of the different groups of learners and provide that group with some level of control and ownership over the content. Provided traceability is in place between the need, structure and content, tailoring may be possible without sacrificing the learning objectives and educational need. Tailoring a course in this way may require some adjustment of the original teaching plan.

Mandatory course content, determined during the design and development phase, must remain in the course. However, it may be possible to design some flexibility into the delivery phase so additional time can be allocated to areas of greatest student interest. Additional time may also be allocated to topics that are proving to be the most difficult for the students, in order to help them understand the material before moving on. This is called a negotiated curriculum.

It may also be possible to discuss available assessment options with students. Negotiating the assessment options with students may reduce assessment anxiety and the subsequent promotion of surface learning. This process could be called negotiated assessment and was discussed along with Ramsden's 14 rules for better assessment (2003) earlier in this section.

4.3.5.5 Making Use of the Learners' Experiences

Some researchers have found that using the experience of mature age students within the class to help provide practical context for the subject is also helpful in demonstrating the practical reason behind a course. This idea has been found to help less experienced students understand the need for the learning and makes effective use of student experience within the group (Dong, 2005).

4.3.5.6 Providing Clear Expectations and Feedback on Progress

Students appreciate understanding what is expected of them and how they are proceeding towards achieving their educational goals. The proposed assessment methods should be made public and explicit at the beginning of the delivery phase of the course (Ramsden, 2003, p. 182). Making the assessment methods and process clear at the beginning of the course may help reduce student uncertainty and anxiety; a factor often associated with promoting surface approaches to learning.

In addition to providing clear expectations, the ongoing provision of feedback throughout the delivery phase is critical. Feedback can take a number of forms such as immediate feedback during discussions in class, and feedback on assessment performance.

Summarising the general progress of the class can also be useful. Maintaining an action item list and publishing it online could do this. At the end of each lecture or logical group of lectures, a summary of the main points can be published, together with the relevant expectations that the lecturer has of the students. These may be more detailed than the learning objectives stated up front. Any points of clarification might be explained and included and any 'homework' expectations/recommendations can be noted as well.

4.3.5.7 Promoting Integrated Learning

The importance of an integrated course structure was discussed in Section 2.3, which outlined student approaches to learning. Structure was shown to be fundamental to promoting deeper learning approaches in students. Surface learners tend to rely on memorising disjointed facts whereas deeper learners are looking towards integrating the separate parts of the material together to appreciate the 'bigger picture'. Presenting the material as a well-structured and inter-related knowledge base supports and rewards students who attempt to adopt a deeper, more integrated approach to learning.

The concept of course structure and detailed course content being related to the course need and learning objectives has been illustrated using a pyramid and the VEE diagram. The top-down approach to design, particularly the ideas of traceability and inter-relationships support the development and delivery of well structured and integrated courses.

4.3.6 The Feedback Loop

Section 3.2.4 described the importance of being a reflective teacher striving for improvement in both the course and in the approaches to teaching used to deliver the course. Figure 4-3 showed that the results of a reflective review at the conclusion of the delivery phase can feed back into any or all of the previous design, development and delivery phases. This feedback facilitates ongoing improvement in the course and its subsequent deliveries. In some cases, reviews may require aspects of the course to be redesigned. This may include the addition, deletion or modification of learning objectives (and the subsequent development effort that results). In other cases, course material, resources or assessments may be found to be unsatisfactory and require redevelopment. In still other cases, aspects of the delivery may need to be adjusted.

The issue of feedback is discussed in Chapter 8 that highlights some of the practical measures of effectiveness that may be used to facilitate this feedback. These include:

- student reviews of the teaching and of the course,
- peer review,
- ongoing demand for the course from the original audience,
- the commercial success of the course and any published learning resources, and
- the adoption and adaptation of the course to meet the educational needs of additional groups of learners.

4.4 The Integrated Conceptual Framework

Figure 4-11 illustrates how the individual elements relate to one another to form the complete framework. The prominent position of the student in the process serves to remind developers of the issues discussed in the literature review regarding the adult student, their experience, and how they learn. In this way, the development process should produce educational activities that have been designed with the adult learner in mind, account for varying learning styles, and promote deeper approaches to learning.

The needs of the 'average' student and their current or future employer determine the need for the educational activity. The need is articulated and the decision is made to develop an educational activity to satisfy the need. This is the start of the lifecycle and results in some design activities represented by the pyramid illustrated in Figure 4-5. The need is at the top of the pyramid and is used to determine the structure and detailed content requirements of the course. Once the design is complete, the development of the learning material can proceed. The material is either sourced from existing material or developed specifically for the activity. The material is arranged into modules in accordance with the design requirements, and then delivered to the student audience. At the end of the delivery process, some form of review occurs that allows the course to be further refined or improved for subsequent deliveries.

The design, development and delivery process is illustrated as a VEE diagram. At any point in the process, verification can identify problems that may require a revision of some or all of the previous work.

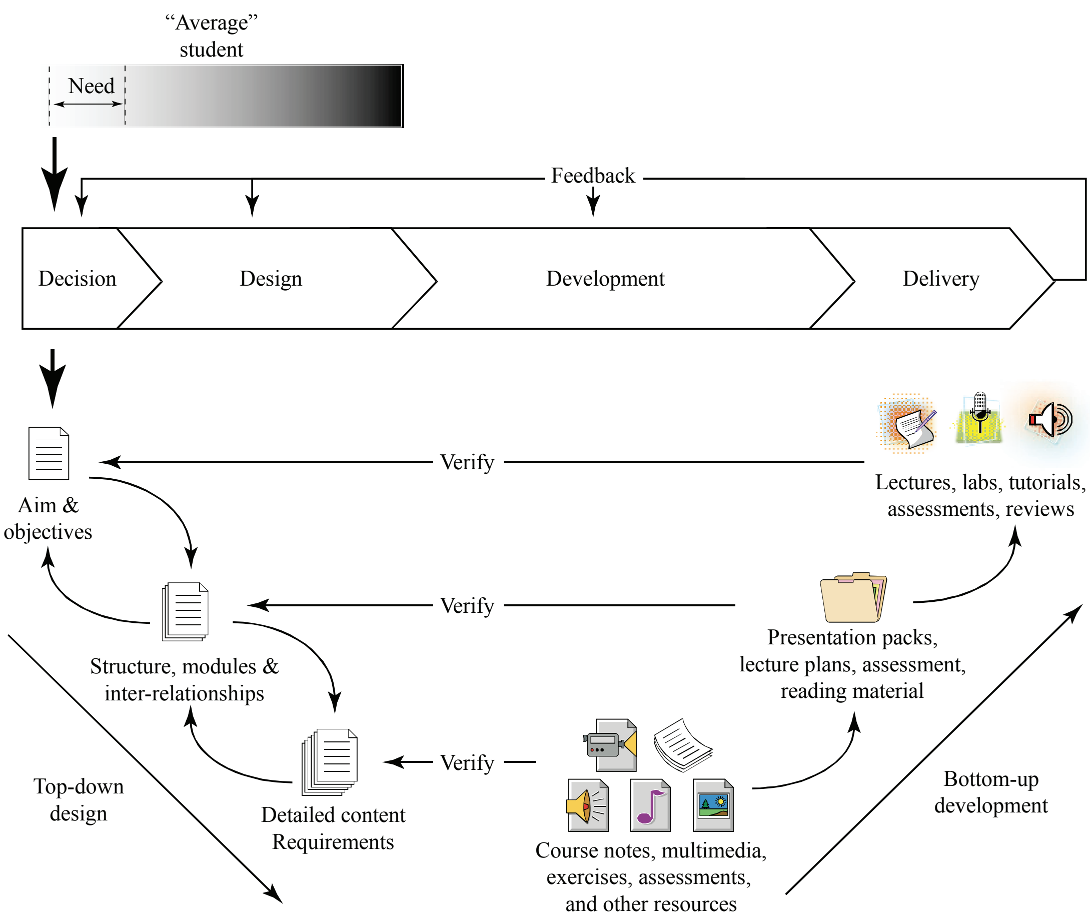

Figure 4-11. Integration of the elements of the development framework

4.5 Conclusion

This chapter has presented and discussed a conceptual framework that can be used to design, develop and deliver effective learning experiences to adult learners. The elements discussed in this chapter were:

- the identification of the need for the educational activity;
- the lifecycle of the educational activity;
- the concept of a knowledge structure flowing from the need and then relating to course structure;
- the design and development of the activity in accordance with established top-down problem solving processes (illustrated by the VEE diagram)
- the delivery of the activity followed by a review of its effectiveness.

It was shown that throughout the design and development process, the developer should be mindful of the aim to promote deeper learning in the adult student, whilst recognising the students' experience, and catering for potential diversity in student learning styles. In this way, the developer is creating a course with the learner in mind and avoiding some of the pitfalls that may encourage surface learning.

Chapters 5, 6 and 7 illustrate how this framework has been applied to the development of three different educational activities.

Chapter 5

Application to the Teaching of Radar systems

5.1 Introduction

Chapters 2 and 3 summarised findings from current literature on aspects of teaching and student learning and teaching. Chapter 2 focused on important issues relating to adult students such as learning styles, approaches to learning, and the role of student experience. Chapter 3 explored the role of the teacher in adult education, investigating teaching approaches, attitudes and attributes that may enhance adult education. Chapter 4 documented a conceptual framework that can be used to design, develop and deliver adult education. Many of the principles discussed in Chapters 2 and 3 were integrated into the framework.

This chapter investigates the application of the conceptual framework to the design, development and delivery of radar systems theory to large groups of non-technical, adult learners. Chapters 6 and 7 also investigate the application of the framework but cover the development and delivery of courses in avionics and systems engineering respectively to different groups of adult learners.

The chapter starts by exploring the characteristics of a group of adult learners that were required to learn about radar systems: warfare officers in the Royal Australian Navy. The nature of modern radar systems is then summarised as a lead into a discussion of how the conceptual development framework was applied to develop a radar course for this group of learners.

The radar course that has resulted from this application has been successfully run for the target audience since 1999. Development and adaptation of the course has continued since 1999 and elements of the course have been used for a range of other educational situations including Masters-level technology awareness courses, undergraduate engineering subjects, and commercial professional development courses. These ongoing developments are discussed further in Chapter 8.

Another major outcome of the application of the conceptual framework has been the writing and publication of an introductory text on radar systems (Faulconbridge, 2002) that uses the content, structure and style developed for the course. Since its publication in 2002, over 1,000 copies of the book have been sold worldwide and the text supports adult education courses in countries including Australia, the United States, and Holland.

5.2 About the Learners

5.2.1 Background, Context and Prior Knowledge

The learners are groups of experienced Naval officers who are undergoing training to become Principal Warfare Officers (PWOs) in the Royal Australian Navy (RAN). PWOs are responsible for the operational aspects of warships through the command and control of the onboard tactical communications systems, weapons and sensors. PWOs normally work within a space on a warship called the Operations Room, and exercise their command and control responsibilities through a system called the *combat system*. The *combat system* on a modern warship is a complex, integrated, real-time information system that provides operators with access to:

- information on the tactical situation around the warship,
- voice and data communication systems, and
- command and control over the weapons systems onboard the ship.

The Commanding Officers (COs) of most major Australian warships are senior PWOs. The PWO course is therefore considered a gateway to higher duties and eventual command within the RAN.

The students who have been on the PWO course are adult learners generally aged in their mid to late 20s, with the occasional student being somewhat older. It is extremely rare for younger students to be on the PWO course, as students must spend a pre-requisite amount of time at sea on operational warships before becoming eligible for selection.

The educational background of the students is also varied. The majority of each group of learners will have a university education (at Bachelors level) but some students will not have formal qualifications beyond high school. The degree-qualified students will generally have a humanities background in fields such as English and history, although some will have science backgrounds in fields such as oceanography or meteorology. It is very rare for engineering qualified students to be on the PWO course as professional engineers are in a different employment category within the RAN.

Although the students' educational backgrounds are generally non-technical, their work environment is extremely technical. They are surrounded by complex technical equipment that they employ on a daily basis. They may also command technical personnel who, in turn, are responsible for keeping the technical equipment serviceable. To that end, the students are technically aware and, due to their operational experience, students come to the PWO course with a number of years of practical radar operation in maritime environments against a range of surface and air targets. They therefore know that radar is a critical surface and air sensor and they also know the capabilities of typical radar systems. The knowledge gap for most students is that they do not necessarily understand the technology or theory behind radar operation, and are therefore unable to explain how radar works. In fact, it is not uncommon for some students to start the course with an incorrect understanding of aspects of radar theory due to ideas they have formulated from observing radar in operation. This is an example of prior experience in adult learners resulting in undesirable habits, bias, or presupposition that was discussed in Section 2.1.4.

5.2.2 Motivation, Attitudes and Approach

The students are generally enthusiastic, motivated and eager to learn, but quickly tire of material that is not demonstrably relevant to their future employment. They are also critical of teaching methods and material that they perceive to be pitched at technical people rather than people with an operational background.

The entire PWO course is almost one year in length (46-48 weeks) and is divided into two roughly equal phases; Phase I is a common phase where general naval warfare theory is taught, whilst in Phase II students specialise in one aspect of naval warfare (air, surface or subsurface warfare). The radar course, which is the subject of this chapter, is a component of a technology module taught in Phase I.

Phase I is assessed by four written examinations each approximately 4 hours long, and one major written examination at the end of Phase I which can last up to 7 hours. The pass mark for these examinations is 80%. The assessment in Phase I is dominated by the need to rote learn extensive amounts of information including lists, tables, operating frequencies, facts, aims, definitions, symbology and codes.

Phase II assessment is dominated by practical assessment in a simulated operations room manned by role-players under the command of the student PWO. This assessment lasts approximately 7 weeks where the student will be exercised 3 to 4 times a week for 1-2 hours at a time. At the conclusion of Phase I and II, the students go to sea on an operational warship for what is called *sea assessment week* where they are assessed in a real operations room.

The PWO course and its assessment produce high levels of anxiety and fatigue in the students. The assessment is designed to place the student under pressure to simulate operational conditions. This anxiety and fatigue promotes surface learning as the default learning approach, and this is evident in the students and their preference for rote learning of lists, definitions and formulas. Surface learning is an undesirable approach to learning about complex and integrated technical systems such as radar, and deep learning approaches therefore need to be encouraged. The literature presented in Chapter 3 indicated that despite these pressures, it is possible to promote and encourage students to adopt deeper learning approaches. Some strategies for promoting and encouraging deeper learning were summarised in Chapter 3. Promoting deeper learning approaches in this course is possible because generally, the PWO students all have a desire to do well in the course. They are usually academically capable of adopting deeper approaches to learning if this is shown to be the key to success in the course assessment regime.

The pace at which the radar component of the course is run, the level and teaching style employed, and the assessment regime are critical in promoting deeper approaches to learning. Other factors used in this course to help promote deeper learning include providing motivational context, increasing student activity and interaction, using a well-structured knowledge base, and providing students with some choice of both material and assessment method.

5.3 Scope and Nature of Modern Radar Systems

Radar, a contraction of RAdio Detection And Ranging, is an electromagnetic system used to detect, locate, and possibly identify objects at great ranges and with great accuracies, in conditions that include darkness, fog and other visual obscurants.

In its infancy, during the early stages of World War II, radar simply detected the presence of targets and provided some basic indication of the targets' location. Modern radar, by contrast, is a very sophisticated surveillance tool that can measure range, bearing and elevation at very long ranges and to very fine levels of resolution and accuracy. The AN/SPS-49 illustrated in Figure 5-1 is an example of a modern naval radar system. It is the primary long-range surveillance radar on RAN ANZAC Class Frigates and has a maximum range of over 400 km, with measurement accuracies of 0.5 degrees in angle and 60m in range (Jane's, 2007). The AN/SPS-49 supports maritime navigation as well as naval warfare applications.

Clockwise from top left is the AN/SPS-49 antenna pedestal, a navigation radar display being used by a ship's navigator, a tactical radar display being used by a combat system operator, and an ANZAC Frigate at sea.

Figure 5-1. The AN/SPS-49 radar system operated by the Royal Australian Navy.
Clockwise from top left is the AN/SPS-49 antenna pedestal,
a navigation radar display being used by a ship's navigator,
a tactical radar display being used by a combat system operator,
and an ANZAC Frigate at sea.
(Photo sources: author and Department of Defence).

Besides range and bearing, modern radar can also measure target speed and the speed of individual elements of the target such as propellers, rotor blades, and turbine fans. This additional information allows modern radar not only to detect a target's presence but also to classify and possibly identify the target. For example, modern operational radars can automatically classify a target as a helicopter as opposed to a fixed-wing aircraft, and in some cases, the radar system can even predict the type of helicopter being detected.

After more than half a century of intensive research and development effort, modern radar systems involve complex transmissions, sophisticated antenna design, and very sophisticated, computer-intensive signal processing.

Whilst traditionally radar was operated as a stand-alone sensor providing a simple display of target range and bearing to the human operator, the modern radar system is rarely employed in this fashion. The modern radar is often just one of many different sensors whose information is combined and processed to provide the operator with a synthetic but very accurate understanding of the situation. The combination and processing of information from multiple sensors to provide a single 'picture' is often called *data-fusion.* Data-fusion improves the accuracy of the information provided to the operator by bridging gaps in the data and resolving inconsistencies. It also provides the information content with some redundancy in the event of sensor system failure.

Appendix B provides a summary of the text on radar systems published as a result of the development of the radar systems course discussed in this chapter. This summary and the text provide some insight into the complexity and application of modern radar systems.

5.4 The Decision to Develop the PWO Radar Systems Course

5.4.1 Introduction

The first step in the conceptual framework introduced in Chapter 4 is to make the decision to develop a given course. This involves establishing the need for the course and documenting any constraints associated with the subsequent design, development and delivery of the course.

5.4.2 The Need for the Radar Systems Course

Radar systems form a critical part of the surveillance capability of a modern warship. Radar provides a host of data about surface and air contacts to the ship's combat system that, in turn, allows warfare officers to detect, track, and engage the contacts with specific weapon systems. Radar systems operate with a finite level of accuracy and can provide ambiguous data. Radar performance is also adversely affected by a host of environmental conditions meaning that its performance as a sensor cannot always be relied upon.

The RAN has determined that PWOs need to understand fundamental radar operation and theory, including an appreciation of the information provided by radar systems to the combat system. PWOs also need to appreciate the accuracy of that information (including any possible ambiguities) and the strengths and weaknesses of radar as a primary sensor. The impact of the environment and climatic conditions on radar performance is also important information for the operational PWO. This knowledge allows the PWO to employ radar systems (effectively and selectively) as part of the broader surveillance capability on a given warship under a range of operating conditions. The PWOs also need to appreciate current and future trends in radar design and performance that may be incorporated in RAN warships in the future to assist them in their future roles as commanding officers in the RAN.

5.4.3 Course Constraints and Opportunities

The following constraints were accommodated when designing, developing and delivering the course:

- the training must take place within one working week, ideally over three 8 hour days of instruction with an examination on day 4.
- the (non-technical) academic background of the students limits the use of mathematics as the primary means of explaining the theory
- the learning resources available to support the course are dependent upon where the course is run (usually in a well-equipped electrical engineering school).

As well as constraints, the PWO radar systems course has some educational opportunities associated with it. Possibly the major opportunity lies in the breadth of practical radar system experience that usually exists within the group of students. Chapter 2 described the important role of student experience in adult learning and the concept that the collective experience of a group of adult learners should be considered an important educational resource. This allows the students to become actively involved in the delivery of the course that, in turn, helps to promote the adoption of deep approaches to learning.

5.4.4 Course History

I was asked to present a pre-existing radar systems course to PWO students in 1999. The pre-existing course was based on traditional approaches to teaching radar systems to technical students who came from an electrical engineering background. The previous teacher (responsible for teaching radar to the PWO course) had attempted to adapt the technical course to the needs of the PWO audience. Feedback that I sought and received from students who had previously completed the course was generally negative and indicated that the adaptation attempts were unsuccessful.

The students cited factors such as inappropriate level and content, the lack of clear relevance to their future employment, and disjointed structure as the main problems with the original course. The students also criticised the course material used to support the existing course. The course material consisted of a collection of photocopied pages from various sources bound together to form the course notes. The material came from a diverse range of sources including photocopied pages from engineering texts on radar, manufacturer's specifications, magazine and journal articles, and hand-written notes and formulas. Because of the diversity of sources, the material also contained inconsistencies in terminology and symbology that further detracted from its value as a learning resource.

The options available to me as the teacher of this course were to:

- run the course as it existed,
- attempt to modify the existing course, or
- completely re-design the course from first principles.

Due to the state of the existing course and the negative feedback it had received from past students, I decided to design a new PWO radar systems course from first principles.

5.5 Course Design

5.5.1 Introduction

Once the need was established in accordance with the conceptual framework presented in Chapter 4 and the *decision* to proceed was made, the *design* phase followed. During the design phase, the need for the course was expanded in order to develop a strong rationale for the course. This information was used later to explain to the learners why they needed to cover the material being presented in the course, thereby enhancing student motivation by situating the learning in a meaningful context.

The meaningful learning context for PWO is the *combat system*, which is a system that integrates a number of critical functions on a modern warship. Modern combat systems are heavily reliant on the performance of their sensors including radar systems. Although the course was about radar systems, by using the combat system as a starting point and explaining the role played by radar in a modern combat system, the context, relevance and practical importance of an understanding of radar theory could be automatically emphasised to the students.

The learning objectives and course structure needed to address the course need were then developed from this learning context. Course material was developed and the course delivered using the aspects of adult learning and teaching discussed in Chapters 2 and 3.

5.5.2 Course Rationale

The relationship between radar and the modern combat system was the main driver in developing the rationale and learning context for the course on radar systems. The objectives, learning outcomes, course structure and content of the radar course flowed from this context. The concept of traceability introduced in Chapter 4 ensured that objectives, outcomes, structure and content could be related to the need for the course via the learning context.

To commence the design process, a mind-map based on an established standard (NATO, 1993) was developed as a convenient way of illustrating some of the many elements of a combat system. A basic mind map of a modern combat system is illustrated in Figure 5-2.

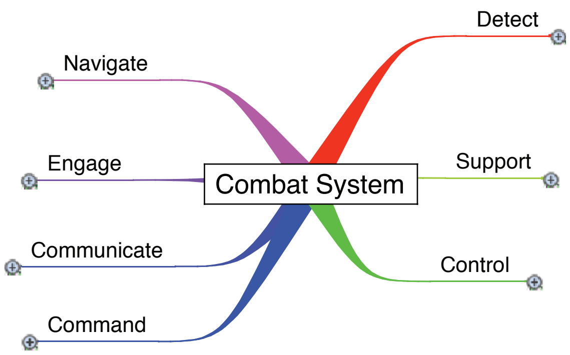

Figure 5-2. Combat system mind map

This figure shows the major functions of a modern combat system including navigation, engagement, communication, command, control, support and detection. There is no significance in the location of the functions shown in Figure 5-2 as they are placed automatically by the mind mapping software for visual clarity.

The main combat system function that is relevant to a course on radar systems is the *detect* function. The *detect* function can be further refined into surface, air, subsurface, and electronic detection because a ship's detection capability is required to provide surface, air, subsurface, and electronic emitter information to the PWOs via the combat system. This is illustrated in the expanded mind map in Figure 5-3.

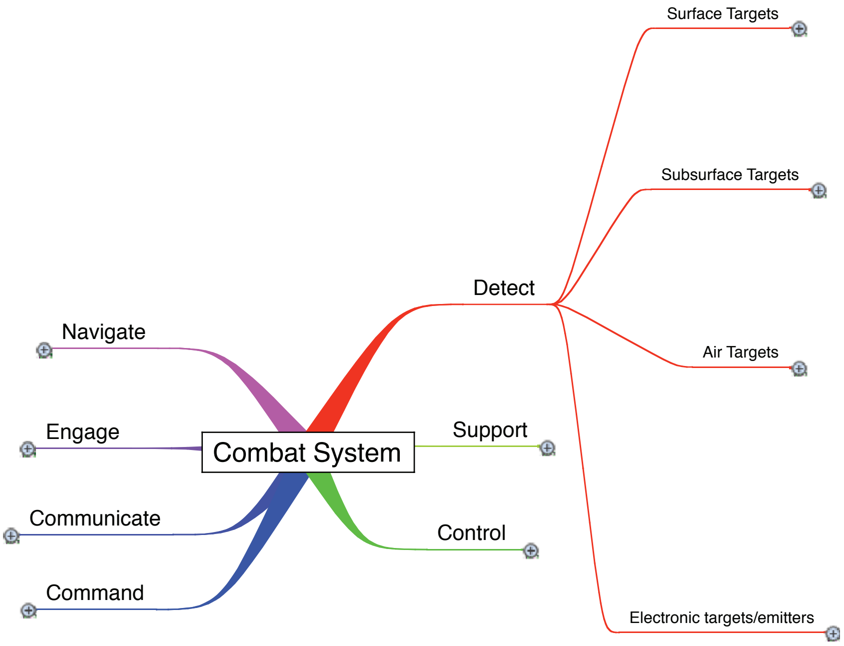

Figure 5-3. Detect functionality

Air surveillance allows targets like helicopters, aircraft, uninhabited aerial vehicles (UAVs), and anti-ship missiles to be detected, tracked, and identified. Depending on the nature of the contact, the combat system uses this information to support other functions such as the engagement of these contacts (in the case of hostile contacts) or command, control, and communication in the case of friendly aircraft. A similar set of requirements exists for surface targets to support engagement, command and control, and navigation. The subsurface 'picture' is also important and consists of the ocean floor, submarines, mines and torpedoes but is not applicable to radar systems (as radar cannot operate under water). Electronic emitters such as an adversary's radar systems can also be detected and located using a combat system's *detect* function.

The typical suite of sensors used to satisfy the combat system's *detect* function on a modern warship includes radar systems, lasers, infrared systems, electro-optic (EO) sensors, and sonar.

Thus, radar supports air and surface surveillance and radar theory also explains how electronic emitters can be detected. The major pieces of information that may be provided by radar for an air target are shown in Figure 5-4.

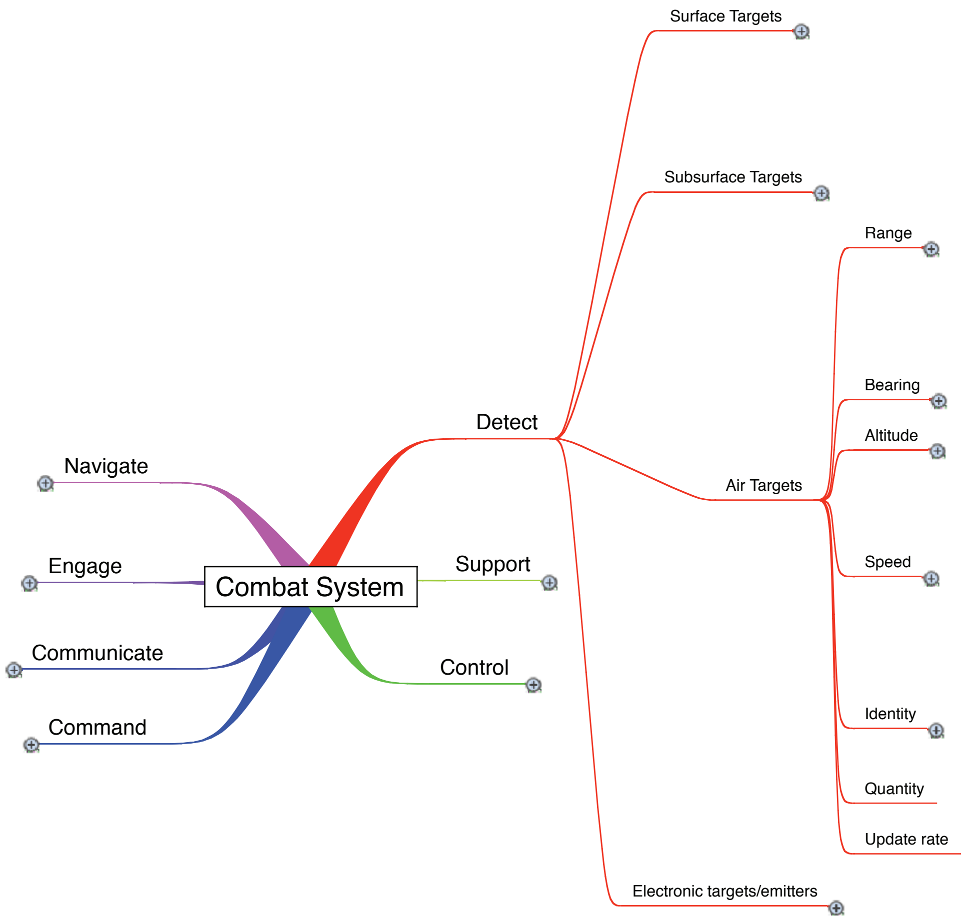

Figure 5-4. Air target information typically provided by radar

From this representation it can be explained that radar systems can provide the combat system with range, bearing, altitude, speed, identity, and quantity of air targets at a given refresh rate. The same set of information (with the exception of altitude) is applicable to surface targets, but has not been repeated here. Similarly, radar techniques can be used to extract information about electronic targets and emitters (for example, the location and type of an adversary's radar system).

For each of these branches in the mind map, there are radar-specific issues that PWOs need to be aware of. Some of these issues are highlighted in a further evolution of the mind map shown in Figure 5-5. This contextualised knowledge structure written from the PWO's perspective is expressed in sufficient detail to inform the next stage of the development of the course.

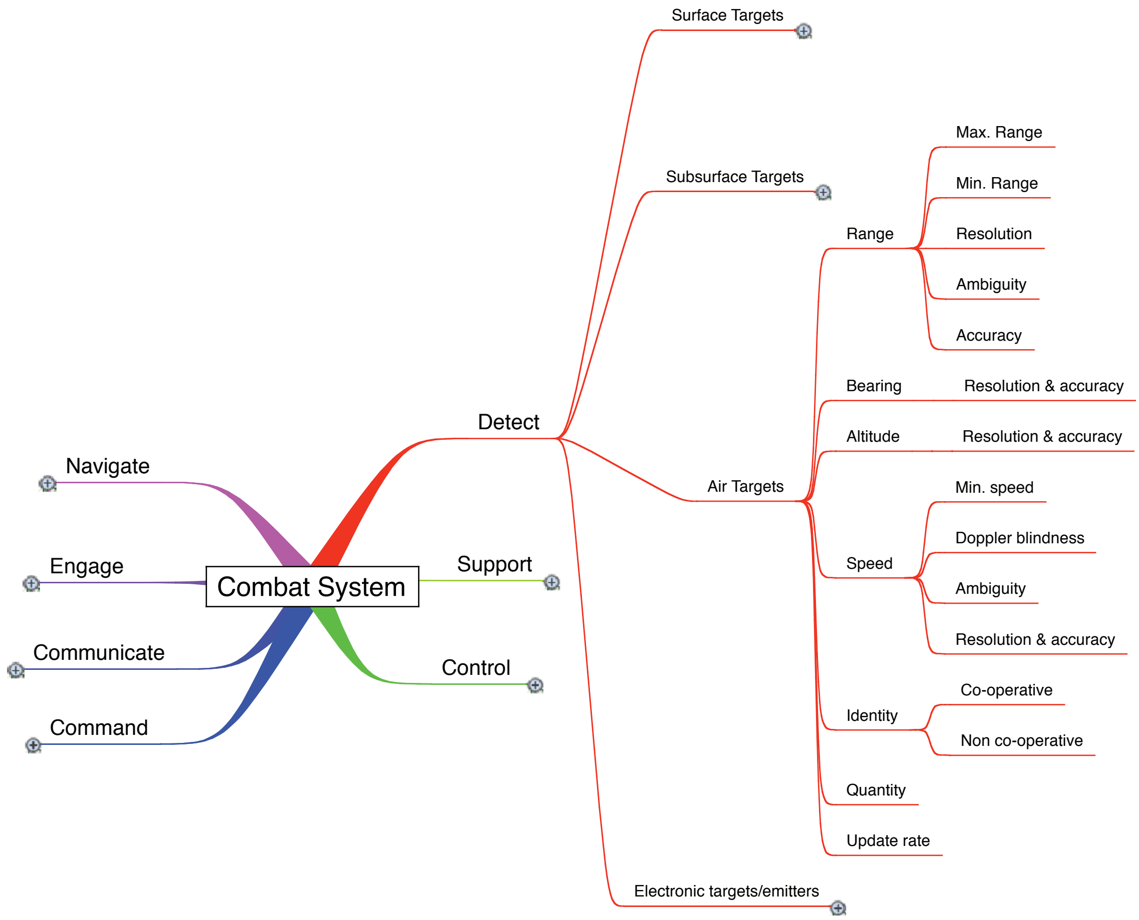

Figure 5-5. Radar-related issues pertaining to air targets

5.5.3 Learning Objectives

From a course design perspective, the radar issues illustrated in Figure 5-5 form the basis of the learning objectives that the PWO radar course needed to achieve.

For example, the first learning objective relating to the detection of air targets shown in Figure 5-5 was for students to be able to explain how radar techniques are used to determine the range of a given air target. This learning objective was expanded further to require the students to explain radar range ambiguity, accuracy and resolution. To know how range is determined using radar techniques, students must be able to calculate the maximum range of a radar system from a target given certain information about the radar, the target and the environmental conditions. The students are also required to explain what determines the minimum range of a radar.

The learning objectives that flowed from this process helped to explain clearly to the students what was expected of them. For example, developing the learning objectives in this way helped clarify whether the students needed to *calculate*, *estimate*, or *determine* the attributes of a given radar system implying a quantitative process, or simply needed to *describe* or *appreciate* the radar attributes using a qualitative approach.

The same process was repeated for the remaining branches in Figure 5-5 in order to develop a comprehensive set of learning objectives. When the learning outcomes had been developed, they were validated via discussions with senior PWOs to ensure that the resultant course was aligned with the needs of the RAN.

5.5.4 Developing Course Structure

Once the learning objectives had been determined, the structure of the course was developed. The structure of the course was informed by:

- A detailed literature review of a selection of the defining texts on radar theory including classic texts by Skolnik (1988) and Stimson (1998). Even though these texts are pitched at advanced undergraduate and postgraduate engineers, the underlying structure of the texts is the result of significant author expertise and experience, and a number of years of revisions.
- Discussions with senior PWOs. As with the learning outcomes, the proposed structure of the course was validated via discussions with senior PWOs.
- Personal professional experience. My professional experience gained from the maintenance and simulation of operational radar systems provided insight into radar theory from an operational perspective.

Each of the major modules in the course structure had a defined role with respect to supporting one or more of the learning objectives and each of the learning objectives was traceable to the original need for the course by working backwards through the mind maps. This is an example of the application of the concept of traceability as discussed in Section 4.2.3. The linkage of learning objectives to course structure can be illustrated in a matrix as shown in Table 5-1. The matrix was used when developing the detailed course content as each module's learning objectives are clear. The learning objectives were also used when evaluating the suitability of the pre-existing radar course, and existing learning resources (including textbooks).

When delivering the course, the mind maps and matrix were used to illustrate the relationships between the learning objectives and the course aim in order to reinforce the reasons for covering the material.

Table 5-1. Traceability between radar learning objectives and course modules

	Major Learning Objectives																							
Major Modules	Radar's role	Radar's context	Range measurement	Range resolution	Min/max range	Range ambiguity	Angle measurement	Angular resolution	Speed measurement	Speed ambiguity	Target identity	Target quantity	Refresh rate	Performance in weather	Performance in clutter	Performance in EW	Radar horizons	Target characteristics	Emitter detection	Emitter location	Emitter identification	Emitter attack		
1. Introduction	■	■																						
2. Pulse Radar			■	■	■	■						■												
3. Radar antennas							■	■				■	■	■										
4. Displays & interfaces	■	■																						
5. Radar range equation					■			■					■					■						
6. CW radar							■		■						■									
7. CW-FM radar			■	■	■	■	■	■	■	■														
8. Pulse Doppler radar									■	■	■	■												
9. Tracking radar							■									■								
10. Pulse compression			■	■	■	■																		
11. Synthetic aperture							■	■			■													
12. SSR											■													
13. Natural Environment					■									■			■							
14. Clutter															■									
15. Radar receivers														■	■	■								
16. Electronic support																			■	■	■			
17. Electronic attack																		■				■		
18. Electronic protection														■	■	■								

5.5.5 Developing the Assessment

As the learning objectives were being written, the assessment method was also developed. This ensured that each learning objective was assessable and that the students would be able to demonstrate achievement of the learning objectives at the desired level. Therefore, the design of the course assessment was simplified by the clear and concise learning objectives. During this part of the course design, it was critical to recall the central role that assessment plays in the learning approach adopted by the adult learner. Anxiety provoking assessment that relies on accurate recall of memorised facts could promote surface learning. A lack of choice with respect to assessment could also be a potentially negative attribute as far as the learner was concerned. The time constraint placed on this course and the requirement for a formal assessment left very little option for assessment other than a written exam. The way in which that exam was designed, explained and presented was aimed at reducing anxiety, providing some level of choice in the questions, and promoting deeper learning by focusing on explanations rather than recall of knowledge and facts.

Sections 2.3.4 and 2.3.5 summarised the role played by assessment in the promotion of deeper learning approaches, and Section 4.2.4 listed some guiding principles that could be applied when designing effective assessment in order to promote deep learning approaches. This information was used to design the assessment and to help students understand the exam process for this course. The specific steps taken with respect to the assessment of the PWO radar systems course are:

- The aim of the exam was introduced early in the course as being an assessment of their understanding, not of their memory. This was emphasised throughout the course.
- The exam was promoted as an opportunity for students to demonstrate what they have learnt and understood from the course. It was emphasised that it should not be considered a threat.
- There was a core of material in the exam that was mandatory for the students to complete, but there was also a fair percentage of the exam that allowed students some choice in what questions they answered. In addition to some choice in the questions they answered, there was also choice in how they answered the questions. Many of the questions could be adequately answered using a combination of explanations, drawings, or formulas depending on student preference. This also helped to cater for diversity in the learning styles of the students as discussed in Chapter 2. Some students preferred the efficiency of mathematics to understand and explain concepts, whilst others preferred the written word, or a drawing.
- The requirement to memorise complex formulas and use them in the exam was something that was found to create anxiety in the PWO students. To help reduce this anxiety, they were provided with a comprehensive formula sheet at the start of the course. This formula sheet was also provided to them in the exam. Therefore, the exam assessed the student's ability to apply the formulae rather than their ability to memorise them.
- Students could expect no surprises designed to trick them in the exam provided they had worked through the case studies and set exercises (either in class or after hours). Again, the exam was merely an opportunity for them to demonstrate their achievement of the learning objectives.
- Students were provided with daily revision questions that were representative of the exam questions. These review questions were a form of formative assessment as they allowed the students to measure their own understanding and progress without the pressure of summative assessment.

If the course was not constrained by time, a more authentic assessment regime may be possible. An example of such a regime may involve individuals or groups of students performing a technical analysis of regional radar systems and providing the class with a presentation of their findings in the form of operational strengths, weaknesses and performance levels. This form of assessment would be a natural extension of the case study work that is currently undertaken during delivery of the existing course as discussed in Section 5.7.

5.6 Development of the Course Content

Once the course structure had been determined along with the associated learning objectives, the course content was identified and developed. This included the detailed development of the exercises and questions that form the basis of review questions and assessment questions. The resources and teaching aids that were to be used during the delivery of the course also needed to be sourced and organised.

As the course was developed for adult learners with a practical but non-technical background, use of demonstrations and practical examples was seen as important. Section 2.3.4 discussed how practical application could motivate students to adopt a deeper approach to learning. Sections 4.2.2 and 4.2.5 discussed how practical course content that relates to the likely future employment of the adult learners could have strong motivational benefits.

5.6.1 Development and Publication of the Radar Text

The other major learning resource required was a textbook. The role of the textbook in this course was to support independent, self-directed study, or study in small groups. To do that, it needed to be consistent with the content and structure of the material delivered in the classroom. It also needed to be written at a level appropriate to the audience, contain sufficient guidance and worked examples, and provide sufficient example questions that would give students opportunities to demonstrate successful achievement of the course learning objectives.

Whilst it was unlikely that the text would be completely read within the one-week time constraint for the delivery of the course, the text needed to allow students to easily access and study specific areas they found difficult. In addition, the text was required to support reflection and future learning by the PWO students after the course was complete.

To do that, it needed to have comprehensive references to allow students to move beyond the introductory level in future if required.

At the time of developing the course, I conducted a thorough literature review of existing radar system textbooks, concentrating on texts that were promoted as introductory texts. I assessed existing texts against the criteria described in Section 4.2.4. The main criticism I had of the existing texts was the level of the content and the assumed prior knowledge required to understand the content. The available texts on radar theory tended to be pitched at a technical audience (professional engineers and engineering undergraduates) and assumed significant electrical engineering and mathematical competence. The available texts also tended to cover additional radar topics not required to support the learning objectives of this course, which was an issue given the short time within which students had to access the knowledge in the text.

Because a suitable text was not available, comprehensive course notes were written against the module structure shown in the matrix in Table 5-1. The course notes (and the course content) were progressively refined between 1999 and 2002. Interviews with senior operational personnel and reviews from various warfare officer courses throughout the period provided valuable feedback. Over this period of time changes were made to the breadth, depth, and style of the notes. When the structure and content became stable, the notes were submitted to a publisher[2] for consideration and were accepted for publication in 2002. An overview of the content of the current edition of the text is at Appendix B. Each section in Appendix B relates directly to at least one of the modules described in Table 5-1.

The text makes use of established techniques to explain concepts, leading to qualitative descriptions where possible including diagrams and drawings. Of course, some quantitative coverage is required, but the quantitative material is at a fundamental level and makes appropriate use of 'rules of thumb' and approximations where these simplify understanding without trivialising the material.

In addition to the fundamentals, each of the chapters in the book provides more enthusiastic readers with references to more detailed information. In this way, the book is a complete resource for the students who require only a fundamental coverage of radar, and an introduction that provides pointers to more detailed information for those students who need a more comprehensive understanding.

The book contains worked examples that are drawn from operational radar systems. This is an attempt to provide readers with an accelerated appreciation of likely system parameters and performance in operational systems. It also ensures that the book is related to

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[2] Argos Press, Canberra, Australia.

real-life situations and likely future employment as discussed in Sections 2.3.4, 4.2.2, and 4.2.5.

Review questions are provided to allow students to continue to develop understanding through practice. The review questions also attempt to highlight the most important aspects of each chapter. This assists revision when assessments include examinations or tests.

The text attempts to explain the rationale behind radar designs, formulas and concepts. The text provides the readers with fundamental mathematical formulas, but also explains how the formulas are derived. This promotes a deeper approach to learning by encouraging understanding rather than memorising. Section 2.3 discussed long-term retention of information as one of the benefits of deeper approaches to learning.

5.7 Course Delivery

The delivery of the course made use of a combination of activities aimed at engaging the adult audience in accordance with the goal of promoting deeper learning. Section 2.3 discussed how course design and delivery could promote deeper learning by:

- providing a motivational context for the students;
- encouraging learner activity;
- facilitating interaction between learners and the teacher; and
- using a well-structured knowledge base for the learning.

The PWO radar system course used a combination of presentations, training aids and demonstrations, group discussions, and individual exercises to engage the students and enable the desired learning to occur.

The course was presented in the module order as shown in Table 5-1. During the presentations, the reason for covering the material was always emphasised and related back to the need for the radar course. This emphasis made use of tools such as the mindmaps and an allocation matrix to reinforce the relevance and practical application of the material. As discussed earlier in this Chapter, the range of experiences that the PWO students had with radar was considered an educational resource and was used where possible to support learning. This helped engage the students, and showed respect for their significant practical experience. It also enhanced the credibility of the material by relating it to real-world experiences.

PWO students share a common belief about electrical engineering subjects like radar: It is difficult to conceptualise something that is not physically visible. The use of some training aids helped with this 'visualisation' and gave the material a more practical feel, which is important for adult learners. The training aids that have been used on this course include an indoor radar trainer, a static radar display, an anechoic chamber, and a multimedia package. Each of these is reviewed below.

The **radar trainer** is an indoor radar system that operates at 9.4 GHz and extremely low power. The trainer includes transmitters, receivers, displays, antennas, and a variety of stationary and moving targets that are mounted on a target table. The system is illustrated in Figure 5-6.

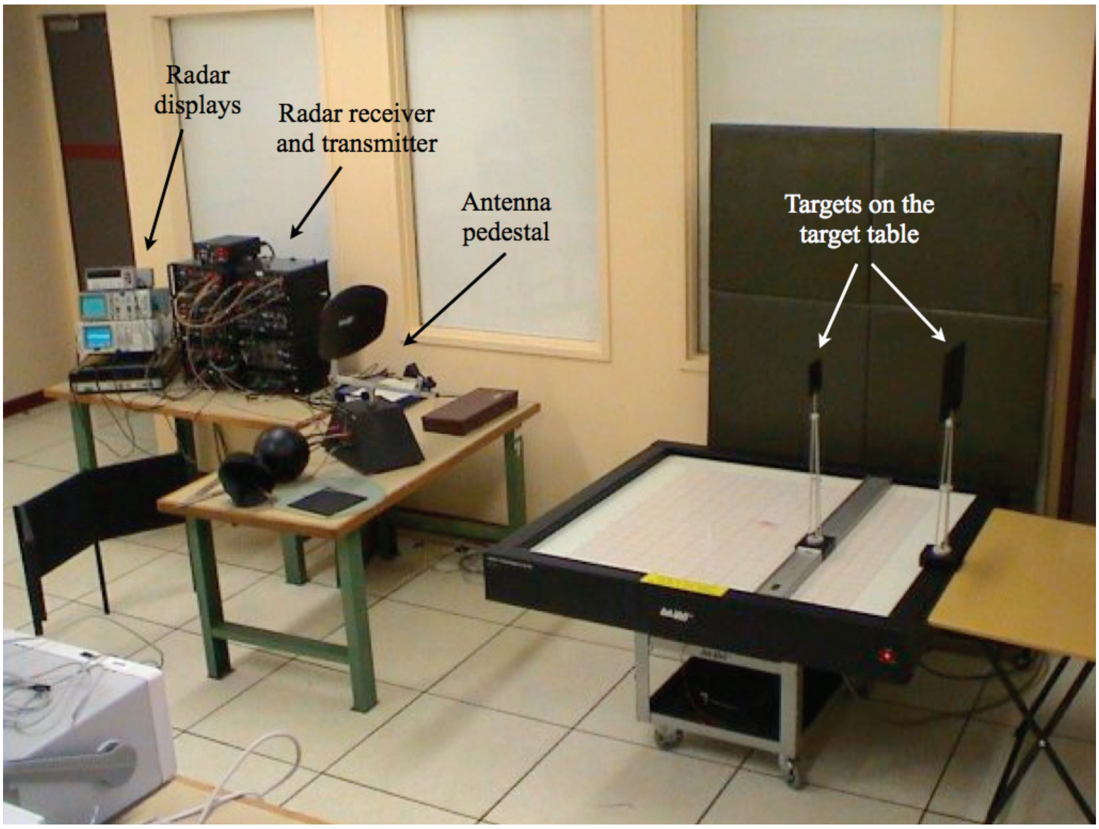

Figure 5-6. The indoor radar trainer consisting of the transmitter, antenna, target, receiver and display.

This trainer allowed a target scenario to be set up and results to be observed. Radar variables can be altered on the trainer and the effects noted and related back to theory. It provides students with the concrete experiences which figure prominently in the experiential learning cycles and models discussed in Chapter 2. The value of the trainer as a learning tool is limited to smaller class sizes (less than 10) where students are able to gather closely around the trainer and observe its operation. Larger classes would need to be broken up into smaller groups to use the trainer, but the time taken for this exercise would begin to conflict with the time constraints for the course discussed in Section 5.4.3. For larger class sizes or when the trainer was unavailable, an explanation and short video of the trainer's operation can be shown to the class. Whilst not as effective as using the radar trainer, the video was considered a suitable substitute that made best use of available resources and time.

Another learning aid that helped relate radar theory to a real system was a **static radar display** conveniently positioned within walking distance of the course venue. This system is illustrated in Figure 5-7. The technical specifications for the radar allowed some of the radar theory to be related to a real system. Students were able to measure the antennas and perform some basic calculations, which correlated with the manufacturer's specification.

Figure 5-7. Static radar system display of a ground-controlled precision approach radar with vertically and horizontally scanning antennas.

Another example of a training aid that provided concrete experiences was an **anechoic chamber**. An anechoic chamber is lined with Radar Absorbent Material (RAM) to minimise radar reflections, allowing it to be used to measure radar antenna performance and target radar cross sections. The anechoic chamber that was available as a training aid for this course is illustrated in Figure 5-8. Practical measurements from the chamber were compared with the results of some simple calculations as a way of demonstrating the link between the theory that was taught and the real situation modeled in the chamber. As with the radar trainer, the anechoic chamber was only used when class sizes allowed. Larger class sizes did not fit in the laboratory, and the timing constraint on the course prevented the conduct of multiple small group exercises in the chamber. In these situations, an explanation of the use of anechoic chambers and associated photographs were used as a substitute.

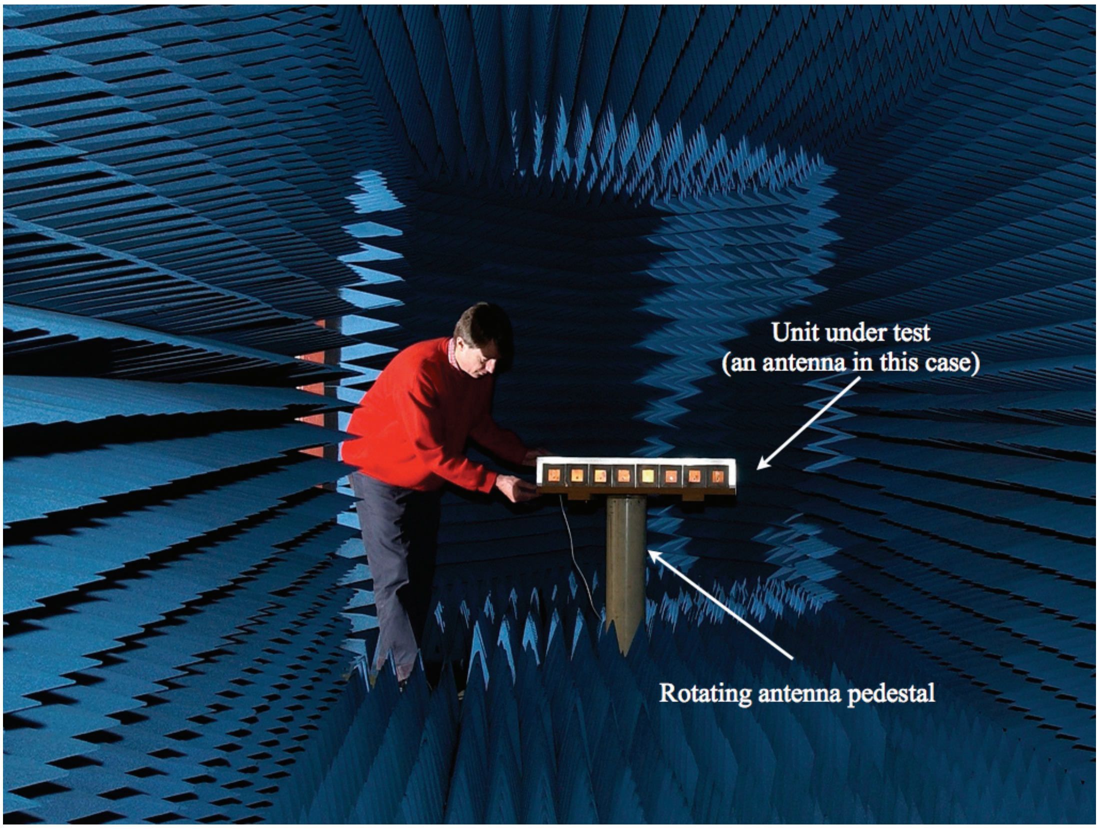

Figure 5-8. The anechoic chamber coated in pyramidal radar absorbing material in order to reduce radar reflections off the chamber walls. (Photo courtesy of David Paterson, ETS UNSW@ADFA)

In more recent courses, a **multi-media information package** produced by a radar company called Thales in the Netherlands[3] has provided some useful animations and illustrations that helped students visualise difficult concepts.

Some of the fundamental concepts of radar operation and theory were neatly illustrated by using the animations and sequences from this package at various points in the course. Students were also able to experiment with this information package to reinforce their understanding, and students were invited to borrow the package to use after-hours to assist in self-directed study. Some students commented on how effective the package was in

[3] *This is Radar – an interactive introduction to radar*, CD-ROM release 1.0, Thales Nederland B.V., 2003

reinforcing their understanding. However, other students did not find the package useful and preferred a mathematical understanding. This may be an example of learning style diversity within the group of learners. It was observed that generally students with an arts or humanities background tended to report benefit from using the package, whereas students with a science or engineering background did not consider the package very useful.

Case studies were used as examples, exercises and for assessment throughout the course. Instead of fabricating examples, the course made use of the radar systems from the students' environments for these purposes. The use of operational radar case studies helped to emphasise the practical application of the theory being covered. Students were often able to describe the actual performance of their ship's radar systems against certain types of targets under given conditions. The material in the course was used to explain this performance and promoted class discussions and debates on possible ways of improving the radar's performance.

5.7.1 Course Evaluation

The RAN collects course reviews at the conclusion of a course. When these reviews suggested improvements or changes, the RAN passed on the suggestions and they were considered. The other way in which improvements were made to the course was by monitoring student assessment results. If students had a problem with a particular area of the assessment, it may have indicated that improvements were required in the course design or delivery in those areas. The idea of improving teaching by monitoring student assessment results was discussed in Section 3.2.4.

5.8 Review

This chapter set-out the design, development and delivery of a radar systems course to groups of adult learners. The radar course was developed in accordance with the teaching and learning philosophies explored in Chapters 2 and 3, and the development framework explained in Chapter 4.

The development of the course was based on an understanding of the learners involved in the radar systems course and the need for the course. The need and rationale for the course were expanded using mind mapping to relate radar systems back to a naval combat system, which provides a meaningful context for the group of learners. This process led to the development of desired learning outcomes for the course. Constraints imposed on the delivery of the course were considered and a structure for the course was developed. The chapter concluded with an explanation of aspects of the course delivery including the use of training aids and case studies.

During the development of the course, a review of available radar texts to support the course failed to identify a text that was ideally suited to the course and the audience. A text was written and published to support the course. Since publication, over 1,000 copies of the text have been sold world-wide. The course and the text continue to be used in Australia, the United States, and Europe to communicate radar fundamentals to diverse and largely non-technical adult audiences.

Chapter 6

Application to the Teaching of Avionics Systems

6.1 Introduction

Chapter 5 investigated the application of the literature review (Chapters 2 and 3) and conceptual framework (Chapter 4) to the design, development and delivery of a radar systems course to groups of non-technical, adult learners. This chapter investigates the application to the teaching of avionics system theory to groups of undergraduate aircrew. This chapter is included to show that the literature review and conceptual framework have been successfully applied to the design and development of a different technical course designed for a different group of adult learners, and to be delivered under a different set of constraints.

This chapter uses the same structure as Chapter 5 for consistency, and therefore investigates the characteristics of the learner first, and then describes the nature of modern avionics systems. The need for the learners to learn about avionics systems is then explored before the course design, development and delivery phases are described.

The avionics systems course has been successfully delivered to the target audience since 2003. In addition, elements of the course are used to support technology awareness courses for groups of aeronautical engineering undergraduates, and also for professional development courses delivered to groups of professionals from the aerospace industry. A major outcome of the application of the conceptual framework has been the development and publication of an introductory text on avionics systems (Faulconbridge, 2007) that uses the structure, content and style developed for the course. Whilst the text has only recently been published and is therefore yet to establish a meaningful sales record, both aviation students and professionals have recognised its value as a teaching resource. The success of this course and the course text are discussed in Chapter 8.

6.2 About the Learners

6.2.1 Background, Context and Prior Knowledge

The learners were groups of aspiring military aviators in their second year of undergraduate study towards a Bachelor of Technology in Aviation [BTech (Av)]. As aspiring pilots, they are interested in the command and control functions of aircraft, and the means by which they can be used to exact the best function and performance from the aircraft and its systems.

When they complete their university study they will undertake flying training with the Australian Defence Force (ADF). Basic flying training takes approximately 1 year and is conducted in two phases; the first phase takes place on basic training aircraft called CT-4Bs in Tamworth, NSW and the second phase takes place on advanced training aircraft called PC-9s at Royal Australian Air Force (RAAF) Base Pearce in WA. Following graduation from flying training, the pilots are streamed onto different aircraft types depending on their abilities and performance during flying training. The options in the ADF include *fast jets* (Hawk, F-111, F/A-18), *transport* (DH-4, C-130, C-17), *maritime patrol* (AP-3C) and others such as air-to-air refueling aircraft and airborne early warning and control (AEW&C) aircraft. Their aviation learning journey does not finish here though, as they are expected to assume greater levels of command as they gain general aviation expertise and experience on their aircraft types.

In terms of the learning continuum illustrated in Figure 2-6, the learners in this course are very much at the *novice* end of the continuum with a combination of formal learning, practical flying training, and operational experience ahead of them to move them towards the *expert* end of the continuum. As discussed in Section 2.1, the students are adult learners and readily appreciate that the formal learning process, of which the avionics systems course is a part, is a key enabler for them to move further along their learning continuum to achieve their career goals.

Due to restricted entry criteria, all of the learners are aged between 18 and 20, a mix of male and female, and are serving officers in either the RAAF or RAN. (Pilot entry into the Australian Army is via a different avenue so the group of learners does not include Army officers.) The selection process for pilot entry into the ADF tends to be extremely competitive and requires successful applicants to demonstrate attributes such as passion and enthusiasm towards aviation.

The learners are in their second year of their BTech studies and therefore have fundamental abilities in mathematics and physical sciences gained from high school and first year university studies. Given that they have chosen the BTech (Aviation) over the more demanding BTech (Aeronautical) it is reasonable to assume that their mathematics and physical science abilities are not at the same level as a 2nd year professional engineering undergraduate. They also tend to exhibit a variety of different learning styles as discussed in Section 2.4.

By the time they reach their second year, the learners have completed some fundamental flying training as part of their degree program. Some of them will be sufficiently competent to have flown solo, and some may have attained civilian flying licenses. Their flying experience is gained in simple aircraft such as the Cessna 182 operated by the School of Aerospace, Civil and Mechanical Engineering (ACME) at the Australian Defence Force Academy (ADFA) at UNSW see Figure 6-1.

Figure 6-1. A Cessna 182 RG like the aircraft flown at the Australian Defence Force Academy (Photo courtesy of Glen Alderton)

Their flying experience gives them a fundamental understanding of aircraft operations and basic aircraft systems. They are aware of the many functions that need to be performed to operate an aircraft and are familiar with the concept of avionics. However, in general, the learners do not come to the course with an understanding of the role of avionics in a modern military or commercial aircraft, nor do they necessarily appreciate the complexity that underpins modern integrated avionics systems.

6.2.2 Motivation, Attitudes and Approach

The learners are enthusiastic about aircraft and approach learning in a very positive manner if they believe the learning will make them more effective aviators and enhance their chances of success in the pilot's course. They view relevant learning activities as opportunities rather than inconveniences. Practical application of knowledge and the relevance of the material to their future careers are keys to their motivation and attitude to learning.

In terms of their approach to learning activities, the surface approach to learning is widely adopted by the learners as they become more exposed to flying. Basic flying training involves a need to learn by rote a number of longs lists and facts, including:

- pre-flight procedures and checks,
- engine start procedures and checks,
- radio frequencies and calls to ground control and air traffic control,
- before flight procedures and checks
- after take-off procedures and checks
- pre-landing procedures and checks

The students are also expected to memorise additional checks and procedures for in-flight situations including engine failure. Students are not encouraged to question the checks and procedures, but merely to know them and be able to recall them quickly. When placed in this learning environment, surface learning is generally adopted as the preferred approach to learning.

The tendency towards surface learning and the non-ideal results of surface learning discussed in Section 2.3 were considered in the design and development of this course, especially in the structure of the course content and assessment. Additionally, approaches to learning and the benefits of deeper approaches were discussed with the students and encouraged during course delivery.

A common view held within the group of learners is that aircraft are made up of a number of discreet and independent systems that operate to provide the aircraft with its function and performance. They often believe that they can completely understand an aircraft's operation by learning about each of the aircraft systems in turn. Whilst this view is valid for older aircraft, it is rarely the case in aircraft designed and built in the last 30 years. The concept of integrated aircraft systems is something that needs to be appreciated by the modern aviator if they are to understand how their aircraft is operating. It follows that a modern aviator is no longer able to learn about or understand aircraft systems as discrete, standalone systems, because the function and performance of individual systems generally always rely on the function and performance of other systems. The function and performance of the modern aircraft is generally greater than the sum of the function and performance of the individual systems because of this level of integration. For example, a modern airborne navigation system may make use of Global Positioning System (GPS), inertial navigation systems (INS), radar, and external navigation aids. The accuracy and reliability of an integrated navigation system are generally better than those of any of the individual elements that comprise that system.

The impact from a learning perspective is that the details or facts on how individual systems operate remain important, but the interrelationships or structure between the systems is becoming increasingly critical. The concept of structure versus facts in a learning situation was discussed in Section 2.3.5 where, for example, the Biggs' idea of a *structure to facts ratio* (S-F ratio) was described. Where facts are more important than the structure, such as learning checklists and procedures, surface learning may be acceptable. However, Biggs concluded that deep approaches to learning are more suitable for subjects with high S-F ratios, such as modern integrated avionics systems. The promotion of deeper learning approaches in the avionics systems course is therefore important.

6.3 Scope and Nature of Modern Avionics Systems

6.3.1 Introduction

As discussed in Section 6.2.2 above, the integrated nature of modern avionics systems is a critical determinant of the instructional approach necessary for effective education of this student group. A review of modern avionics is described here to support the decisions made and development work undertaken in subsequent sections of this chapter.

6.3.2 Modern Avionics Systems

Aircraft comprise a number of different systems. Typical major systems include the engines, the airframe, the hydraulics, and the undercarriage. Avionics is another major system on a modern aircraft that is becoming increasing critical and complex, as more and more aircraft functions are performed by onboard electronic systems.

The term *avionics* is a contraction of AVIation electrONICS. Modern avionics systems represent the complex combination and integration of a number of sensors, displays, controls and computer systems performing a diverse range of tasks. Aircrew who operate modern aircraft need to understand thoroughly their avionics systems in order to get the most out of their aircraft and respond appropriately to in-flight incidents, unserviceabilities or emergencies. The complexity associated with modern avionics systems is evident to the non-expert by looking at a typical cockpit arrangement as shown in Figure 6-2.

Figure 6-2. Cockpit of the U2 aircraft showing the myriad of displays and controls typical in a modern aircraft (photo courtesy of the United States Air Force).

Critical aviation functions typically performed by avionics systems include:

- **Flight control.** The stability and comfort of modern aircraft is normally augmented by digital computer systems known as digital flight control systems. These systems also allow the aircrew to control the aircraft and engage other critical systems such as an auto-pilot.
- **Communication.** Modern aircraft need to be able to communicate by a variety of means include voice and data communications. The communication

requirements could include communication within the aircraft (between aircrew and passengers for example), communication with air traffic controllers over vast distances, and even computer-to-computer communication between two co-operating aircraft. These requirements are met by communication systems involving voice radios, satellite communications, and data links.

- **Sensing the environment.** Aircraft sensor requirements extend from very fundamental sensors like air-data sensors that measure pressure and temperature, gyroscopes and accelerometers that measure angular and linear accelerations, to the more advanced infrared sensors and radar systems. The sensors are used to provide information about the aircraft and its surrounds to other parts of the avionics system and to the aircrew.
- **Identification.** Being able to identify oneself to appropriate authorities is critical for both civilian aircraft (for purposes such as air traffic management) and military aircraft (to avoid mistaken identification and engagement). This process is generally automated but relies on appropriate initialisation by aircrew before and during flight.
- **Navigation.** Aircraft navigation is often referred to as 4-dimensional navigation, which relies on an accurate understanding of aircraft longitude, latitude, altitude and time. Avionics systems assist in controlling and managing the current and future location of the aircraft by using an array of techniques such as dead-reckoning navigation and reference to external systems such as navigation satellites.

An appreciation of avionics systems requires an understanding of the functions expected of avionics systems and the means by which the functions are delivered. The latter involves an understanding of cockpit systems, sensors, computer hardware and software, airborne data networks, and the generation and distribution of electrical power.

Historically, avionics system functionality was delivered via standalone systems onboard aircraft, each with their own controls and displays as required. This approach to avionics system design is known as *independent architecture*. As computers and computer data networks started to emerge in the 1970s, avionics architectures started to take advantage of the flexibility of loosely networked computers. Aircraft avionics systems started to resemble a basic computer network where each computer performed a defined role of the aircraft (such as navigation) but shared data with other computers. These architectures were known as *federated architectures* or *second-generation architectures.* Through the 1980s and 1990s architectures started to become physically simplified via a reduction in the number of computers and greater reliance on high-speed data sharing. Each computer took on more and more avionics systems functions by virtue of the software running on the computer. These architectures are known as *integrated architectures* or *third-generation* architectures. Although physically simplified, these architectures have increasingly complex software and data networks. The current trend of integration continues, and aircraft currently under development are taking integration further by sharing displays, controls and even antennas across multiple functions. These aircraft are said to have *advanced integrated avionics architectures* or *fourth-generation architectures.*

Additional information regarding modern avionics systems is at Appendix C, which provides a summary of the text on avionics systems published as a result of the development of the avionics systems course discussed in this chapter. The text provides some insight in the complexity and levels of integration in modern avionics systems (Faulconbridge, 2007).

6.4 The Decision to Develop the Avionics Course

6.4.1 Introduction

The decision to develop a course is the first step in the Chapter 4 framework. The need for the avionics systems course and the constraints and opportunities associated with it were the first issues considered and are documented in this section.

6.4.2 The Need for the Avionics Course

A modern aircraft is a complex combination of systems that need to work together to deliver functionality to the aircrew. In order to operate modern aircraft safely and effectively, aircrew must have a thorough understanding of how their aircraft flies and how their aircraft's systems operate and inter-relate. This understanding allows the aircrew to operate the aircraft under normal conditions, but also allows them to fault-find and operate under adverse conditions such as those caused by the environment or aircraft system malfunctions.

The avionics system is only one of many systems on a modern aircraft, but it is a system that is taking on increasing significance as modern designs rely more and more on computational power, sophisticated sensors, and voice and data communication with the ground and other aircraft.

When the ADF eventually takes delivery of the Joint Strike Fighter (JSF) in the years to come, every generation of avionics architecture (from 1st to 4th) may be simultaneously represented in the ADF fleet. With reference to Figure 6-3, the DH-4 Caribou is an example of an independent avionics architecture, the F/A-18 Hornet uses a federated architecture, the C-130J Hercules has an integrated architecture, and the Joint Strike Fighter design incorporates an advanced integrated architecture. Future pilots in the ADF will therefore require a broad and thorough understanding of avionics systems in order to be sufficiently flexible to learn about these aircraft types. Learning and understanding a single generation avionics system design and operation will not adequately prepare the student pilots for their future employment.

Figure 6-3. Current and future aircraft of the ADF. Anticlockwise from top left, Caribou DHC-4 (1st generation), F/A-18 Hornet (2nd generation), C-130J Hercules (3rd generation), and Joint Strike Fighter (4th generation). (Images courtesy of the RAAF and USAF)

When ADF pilots start to fly a particular aircraft type, they complete a *conversion course* on that aircraft type where they are expected to become expert quickly in the onboard systems and their operation. They normally attain this expertise through a combination of flying experience and the study of the detailed operating instructions for that aircraft (usually called the *flight manual*). A flight manual is a structured and detailed document that contains technical and operational information about every system onboard the aircraft and how they integrate to form the complete aircraft system. Flight manuals are written assuming that pilots have a sound level of general aviation knowledge. Without this background knowledge, a knowledge gap exists, making it extremely difficult to grasp the flight manual.

The modern aviator needs to understand their aircraft thoroughly and must also maintain an awareness of trends and developments in modern avionics systems that may be employed in the future. This understanding and awareness will make them better able to operate their aircraft under a range of conditions, and to assume command positions responsible for making decisions about future aircraft acquisitions. The RAAF and RAN have recognised this need, and require undergraduate pilots studying a BTech (Aviation) to complete a course in avionics systems as an important enabler prior to commencing basic flying training.

6.4.3 Course Constraints and Opportunities

Time is the primary constraint in the delivery of this course. The avionics for aviators course was limited to 27 contact hours and a 3-hour exam allocation in the examination period. It was taught over one academic session at a rate of three hours per week. There were no allocated resources for laboratory exercises.

The main opportunities associated with the course related to the enthusiasm and passion for aviation shown by the vast majority of the students as discussed in Section 6.2.1. They tended to be motivated easily by material that was directly related to their future as military aviators. Whilst there was natural variation across the groups with respect to personality, prior experience, learning style and approach to learning, most of the learners tended to enjoy becoming actively involved in the learning process because it was directly related to their chosen profession. Their enthusiasm assisted in promoting deeper learning approaches during the delivery of the course. They were a different group of learners from the PWOs discussed in Chapter 5 because they were considerably younger, and had less general domain experience than the PWO learners. In terms of the continuum illustrated in Figure 2-6, these learners were avionics novices.

6.4.4 Course History

Before this course was designed, the BTech (Av) students studied an avionics systems course that had been developed for 4th year undergraduate electrical engineering students. The level and content of this course befitted an electrical engineer in their final semester of undergraduate study and relied heavily on fundamental mathematics, physics and general electrical engineering knowledge. Not surprisingly, the university found that the 4^{th} year engineering undergraduates and the 2^{nd} year aviation undergraduates had significantly different academic backgrounds and capabilities. The two groups of learners also had different educational requirements for a course on avionics systems. The engineering undergraduates needed a more technically focused course whilst the aviators needed a course focused more on the theory of aircraft operation. Student feedback indicated that both groups of learners felt that the course failed to address their educational requirements and expectations adequately because of compromises that needed to be made for the other group. Accordingly, in 2003, it was decided to split the courses and a new course was developed that was designed specifically for aviators.

The design of this new course is discussed in the following section.

6.5 Course Design

6.5.1 Course Design Philosophy

As mentioned, pilots need to be aware of all of the systems on their aircraft, how they work and how they interrelate. The students all have flying experience before they start this course and are able to list and discuss the major systems on a modern aircraft.

The course design process commenced by adopting a *functional* view of the aircraft concentrating on *what aircraft need to be able to do* in order to fulfill their missions. The functional view was then used as the basis of the knowledge structure and learning objectives for this course. In contrast to the knowledge structure, the structure and content of the course was determined using a *systems* view of an aircraft in order to examine *how the aircraft systems deliver the functionality* that is required.

By relating aircraft functionality to the avionics systems that deliver that functionality, the reasons for learning about the avionics systems become clearer. The relationship therefore emphasises the relevance and importance of avionics systems, and the rationale for learning about avionics systems.

6.5.2 Course Rationale and Overview

The critical role played by avionics in delivering functionality to modern aircraft forms the basis of the need for the avionics systems course. In accordance with the framework presented in Chapter 4, the course objectives, learning outcomes, structure and content flow from, and are related to, this need.

To start the design process, I used my aviation background to develop a mind map that illustrated the core functionality of a generic aircraft to which student aviators would be able to relate. This formed the basis of the knowledge structure of the course and is illustrated in the mind map in Figure 6-4.

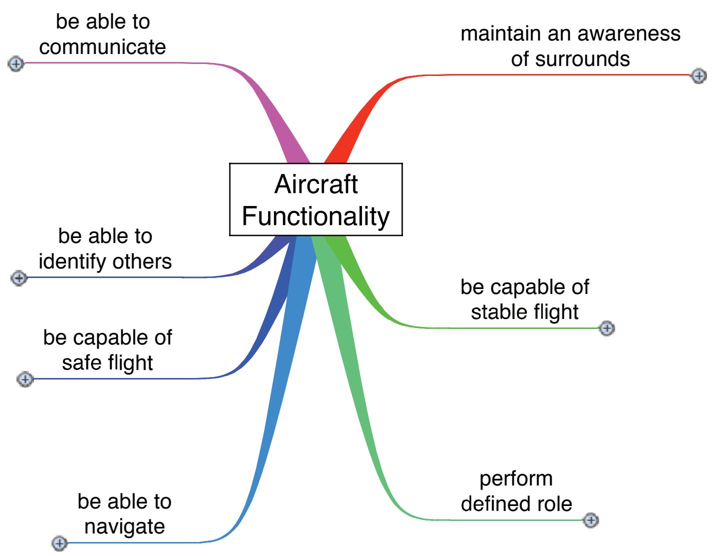

Figure 6-4. Aircraft functionality mind map.

This figure shows the major functions of a generic aircraft. There is no significance in the location or order of the functions shown in the mind map. Working around the mind map in a clockwise direction, all aircraft need to be able to communicate with other aircraft and with entities on the ground such as air traffic controllers. Aircraft also need to be able to maintain an awareness of their surrounds, including the weather, other aircraft, and atmospheric conditions. Aircraft also need to be able to fly in a stable fashion in order to maintain comfort for passengers in the case of commercial aircraft, or to provide stable weapons and sensor platforms in the case of military aircraft. Every aircraft will have a defined role from which additional "type specific" functions are defined. For example, the role of a commercial aircraft is to transport people and freight from one place to another. The role of a military aircraft may be to carry out reconnaissance of the earth under all weather conditions. All aircraft need to be able to navigate from one place on the earth to another place, and these places may be thousands of kilometers apart. In addition, aircraft need to perform this navigation within certain time constraints in order to meet air traffic control or operational imperatives. All aircraft need to be safe. Aircraft accidents can lead to devastating loss of life so the reliability of modern aircraft needs to be extremely high. Finally, the mind map in Figure 6-4 lists the ability of aircraft to identify other aircraft as being important. Air traffic controllers and military operators rely heavily on aircraft providing information relating to their identity. This assists in airspace control, prioritisation, and (in the military context) targeting.

Figure 6-4 was then expanded to provide additional insight into the necessary functionality of a generic aircraft in order to support the development of learning objectives.

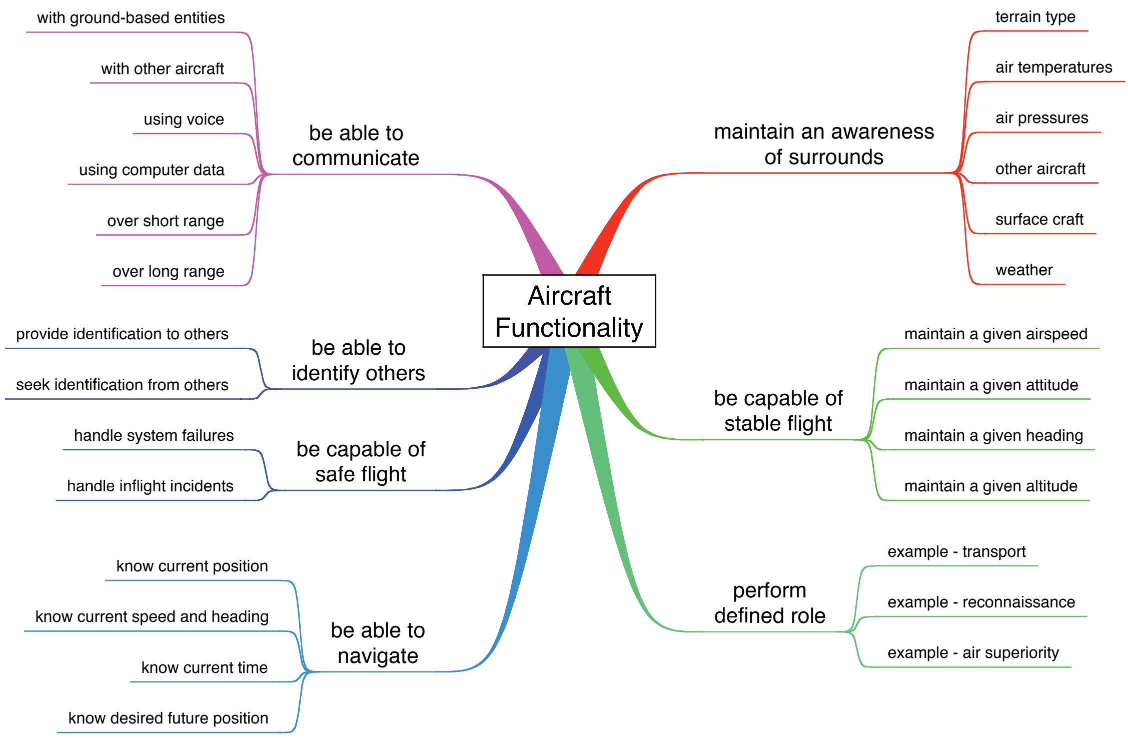

Figure 6-5. Expanded aircraft functionality mind map.

By starting with the necessary functions of a generic aircraft rather than starting with the technology that delivers it, students with little or no prior aviation experience are able to appreciate the tasks that need to be performed by the aircraft systems. Additionally, as discussed in Section 4.2.3, this approach provided a meaningful knowledge structure for adult students to assist them to appreciate the need for the course.

The next step in developing the course was to determine the learning objectives based on the functionality of a generic aircraft.

6.5.3 Learning Objectives

The broad aim of the avionics systems course was to discuss how modern avionics systems deliver some or all of the functionality shown in Figure 6-5. Therefore, Figure 6-5 was also used to develop the main learning objectives of the avionics systems course.

Using airborne navigation as an example, students needed to know how aircraft determine their current position in terms of latitude, longitude and altitude. Firstly, in general, the students did not fully understand the meaning of these terms. Therefore early learning objectives needed to cover fundamentals such as the earth's geometry and the different frames of reference that can be used to define an aircraft's location.

Secondly, airborne navigation can be performed using one of two techniques; and each needs to be understood by the students.

- Dead reckoning navigation involves knowing the aircraft's starting position, and maintaining a calculation of how far and in what direction the aircraft has traveled. Inherent in these calculations is knowledge of aircraft speed and direction, so learning objectives associated with airborne navigation included students being able to explain the different ways in which aircraft measure their speed and direction.
- Reference to external entities with a known location is another major form of navigation that ranges from manual observation of known features (such as mountains or cross-roads) and relating them to a map, through to GPS navigation. Learning objectives associated with an external reference system related to how an aircraft is able to determine its range and bearing from a particular entity (be that electronic such as a GPS satellite or physical in the case of a mountain) and then use that information to determine its own position.

Each learning objective contained sufficient detail to explain to students what was expected of them. In Section 4.2.2, the presence of a suitable verb in the learning objective statement was discussed as being important for this reason. For example, students needed to know whether a learning objective involved them performing a quantitative process or whether the objective involved a qualitative approach. The learning objective also made it clear what the student would have available to perform the task.

Continuing the airborne navigation example, aircraft must be able to determine their speed and heading in order to perform basic dead-reckoning navigation. Therefore a quantitative learning objective required students to be able to calculate the airspeed of an aircraft. This is used as an example in the next section (Section 6.5.4).

An associated qualitative learning objective required students to be able to explain how basic dead-reckoning navigation can be performed using ground speed and true heading.

The major branches in Figure 6-5 were used in this way to develop the course learning objectives. The course structure was then developed in order to deliver the learning outcomes of the course.

6.5.4 Course Structure Development

The first step in determining the course structure was to place avionics systems into context with other (mechanical) aircraft systems typically found on aircraft. Flight manuals were found to be a useful reference for this, however most flight manuals, especially military flight manuals, are not publicly available. (As this course was designed for military students, military flight manuals were made available to students during the course as a learning resource. This is discussed further in the section on course delivery). No restricted military flight manuals were used in the design or development of the course, however older flight manuals that were publicly available were used as reference sources. For example, the F-111F flight manual was recently made available for public release by the United States Department of Defense (T.O.1F-111F-1, 1979).

The mind map used to show the major aircraft systems and highlight the context of avionics systems in relation to the other aircraft systems is illustrated in Figure 6-6.

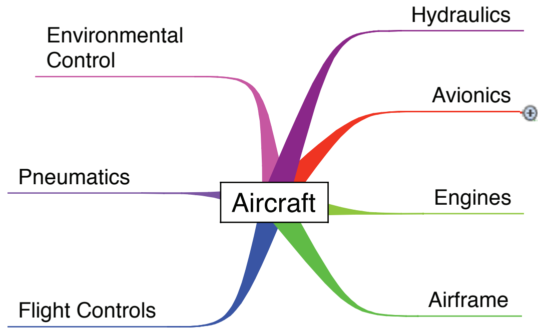

Figure 6-6. Avionics systems in context with the other aircraft systems.

Due to the course time constraint discussed earlier, coupled with the breadth and complexity of the avionics discipline, a decision was needed with respect to depth of coverage versus breadth of coverage of avionics topics. One of the aspects of course design discussed in Chapter 2 that tends to promote surface learning in students is the lack of opportunity to cover material in depth during a course. This problem can be caused by trying to cover too much material in a course. With this in mind, I decided to limit the coverage to the major avionics systems of relevance to the students, and to cover those systems to a level of detail appropriate to the desired learning outcomes, student capabilities and their likely future employment paths. In making this decision, I used my professional knowledge and aircraft flight manuals to determine the potential avionics systems that should be covered. Operational aircrew consulted during the design process then validated this list of avionics systems.

Figure 6-7 shows the avionics systems that were eventually incorporated into the course. Within each of the avionics systems shown in Figure 6-7, further detail was required in order to support the development course structure and content. An example of this detail is shown in Figure 6-8 where some of the avionics systems have been expanded. (Not all details have been included in order to maintain clarity in the illustration.)

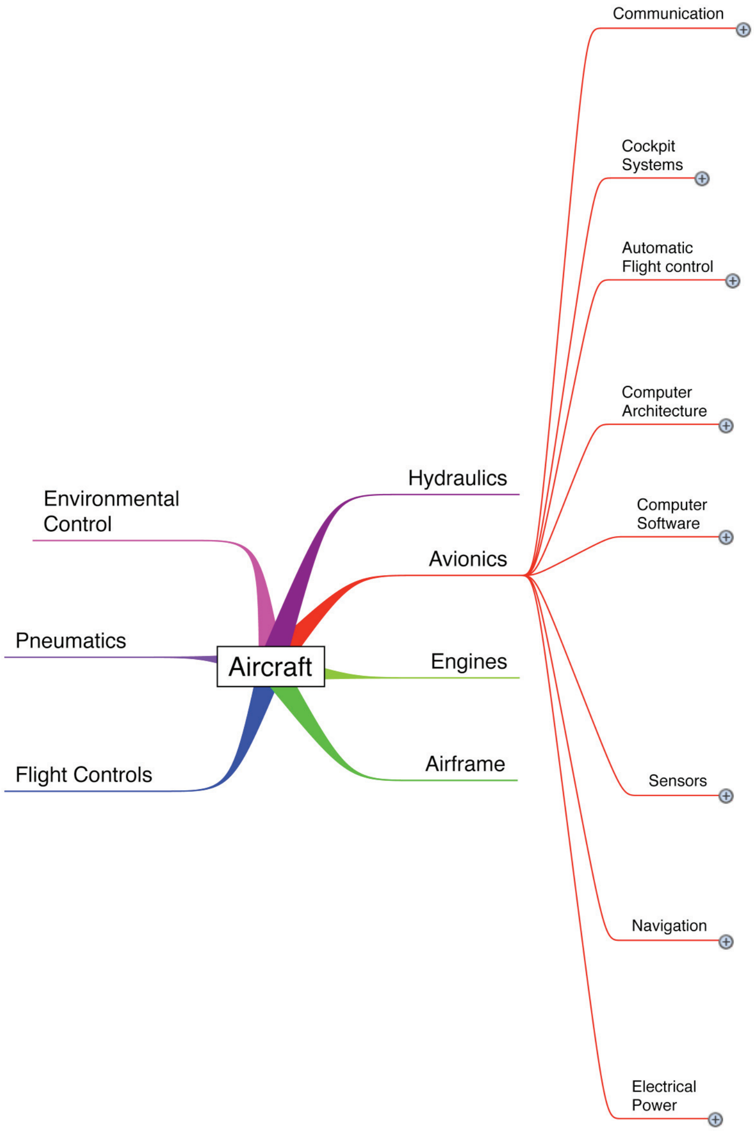

Figure 6-7. The avionics systems incorporated into the course.

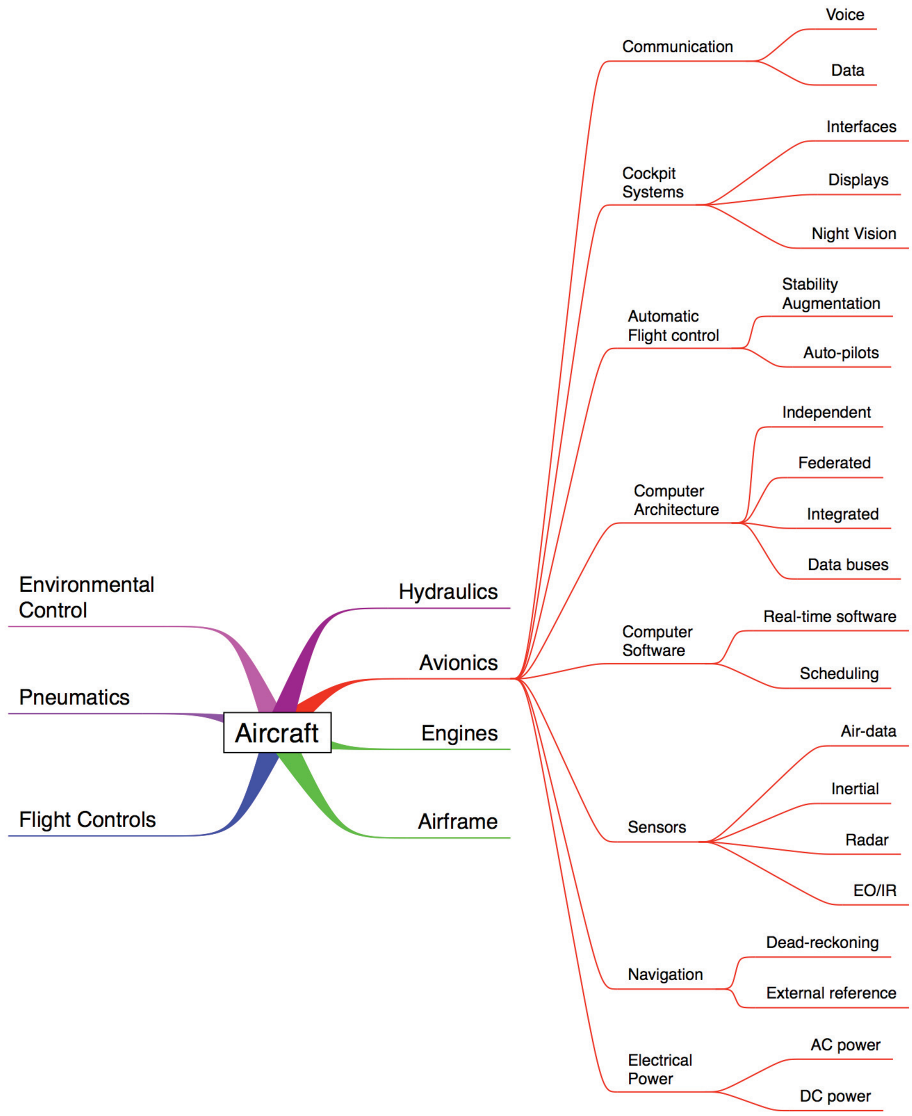

Figure 6-8. Expanded avionics system detail to support development of learning objectives

When the avionics systems had been expanded in this way, the traceability (or allocation) matrix was developed to show how the broad learning objectives influenced the required content of the individual modules. The importance of traceability and the concept of a traceability matrix were described in Section 4.2.3.2. The traceability between learning objectives and the course modules is illustrated in Table 6-1.

Each of the modules shown in Table 6-1 and the way in which they address the allocated learning objectives are explained in more detail in Appendix C.

Table 6-1. Traceability between avionics learning objectives and course modules.

Major Modules	Major Learning Objectives: Avionics in context	Awareness of terrain	Current temperature	Current pressures	Detect aircraft & vehicles	Awareness of weather	Maintain airspeed	Maintain heading	Maintain altitude	Maintain attitude	Current position	Current speed/heading	Current time	Desired future position	Flight safety - failures	Flight safety - incidents	Identity of others	Identity of self	Voice communication	Data communication	Long/short range comms	Defined Roles
1. Introduction	■														■	■						■
2. Electrical Systems	■														■	■						■
3. Flight Control System							■	■	■	■				■	■	■						■
4. Air Data Systems			■	■								■			■	■						■
5. Inertial Sensors											■	■			■	■						■
6. Radar		■			■	■					■	■			■	■	■					■
7. Electro-optics		■			■										■	■	■					■
8. Communication					■								■		■	■	■	■	■	■	■	■
9. Navigation Systems		■									■	■	■	■	■	■						■
10. Computer Systems	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
11. Avionics Software	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
12. Cockpit Systems		■	■	■	■	■					■	■	■	■	■	■			■	■		■

Some of the course modules identified in Figure 6-7 did not strongly relate to many of the learning objectives, whilst others seemed to relate to all of the objectives. These modules were examples of important avionics *enablers* rather than direct providers of avionics functionality. Examples of enabling systems included in the content were:

- aircraft electrical systems that provide electrical power to all aircraft avionics systems but do not deliver any avionics functionality as such,
- onboard computer systems, data networks, and software that perform many of the calculations and processing associated with avionics systems, and
- cockpit systems consisting of displays and interfaces that allow aircrew to interact with the avionics systems.

The enablers were not as high a priority as the modules that taught the avionics system theory behind the delivery of specific aircraft functionality. Whilst it was preferable that the entire course content be delivered, it was found that the enablers could be succinctly summarised or covered as background reading without having a major impact on the delivery of the learning outcomes. Note that this approach was possible because this course was not time-constrained like the radar course described in Chapter 5, therefore students were able to do background reading prior to classes. This provided some significant flexibility during course delivery. For example, more time could be spent on modules that generated significant student interest.

In addition, some of the learning objectives were linked to all of the modules. When a learning objective was allocated to many avionics system modules, it indicated that a general theme needed to be impressed upon the students during the entire course. For example, Table 6-1 illustrates that system safety was a learning objective that influenced all avionics modules, as all avionics systems contribute to aircraft safety. The design and operation of all avionics systems must therefore take safety into account.

Once the learning objectives had been linked to the course structure in this way, both the learning objectives and course content were revisited to ensure all of the learning objectives would be addressed by the content, but that no unnecessary content was being covered. By revising the learning objectives in this way, adjustments were made to some of the learning objectives and some of the course content, in order to guarantee tight traceability between learning objectives and course content.

The learning objectives were also expanded at this stage into detailed competencies to clarify what each module needed to contribute to the course. An example of this expansion was the learning objective relating to *measuring aircraft speed*. Aircraft speed can be determined in a number of ways. In this course, only the three main ways of measuring aircraft speed were covered. Using the allocation matrix for this course, measuring aircraft speed was allocated to the modules on *air data systems*, *radar*, and *inertial systems*. These three avionics systems calculate speed in different ways, therefore more detailed learning competencies relating to aircraft speed were developed in these three modules. Air-data systems, for example, measure pressure and temperature and then use these measurements to calculate speed. For the air-data system the detailed learning competency became:

> *Students must be able to calculate the ground speed (in knots) and the true heading of an aircraft given:*
>
> - *Aircraft static pressure in kPa*
> - *Aircraft total pressure in kPa,*
> - *Total temperature in K,*
> - *Aircraft heading,*
> - *Wind speed and direction, and*
> - *Course formula sheet.*

By revising the learning objectives in this fashion, the learning objectives became clearer from the students' perspective, more assessable from the course design perspective, and hinted at some course resources that needed to be developed (in this case, a formula sheet).

This revision was an example of feedback in the lifecycle model and VEE diagram described in Chapter 4 and illustrated in Figure 4-3 and Figure 4-10 respectively.

Another design issue that was addressed during this stage was the order in which the avionics subjects should be presented. Apart from the introductory, context-setting material and the conclusion, the presentation order was not immediately obvious. To determine the presentation order, I used my knowledge of integrated avionics systems to determine how best to present the material. The order that was found effective is illustrated in Table 6-1 and described in Appendix C.

Because of the high level of inter-relationship between the different avionics subject areas, the early modules were taught before the related modules had been covered. For example, automatic flight control, taught early in the course, relied on information provided by systems such as air-data systems and inertial sensors, which were covered later in the course. This issue was addressed by providing students with a thorough introduction of the modules to be covered at the start of the course, making it possible to treat systems covered in later modules as 'black boxes' during the earlier modules.

6.5.5 Developing the assessment

Section 2.3.1 showed that deeper learning is likely to be longer lasting than surface learning, and this means that deeper learning is a more desirable approach to learning. The role of assessment in promoting deeper approaches to learning was discussed in Sections 2.3.4 and 2.3.5. The assessment for this course was constrained by the timescale within which the course was presented, the workload on the students, and the lack of laboratory access. The anxiety of the students associated with large, formal examinations carrying the bulk of the subject's marks also influenced the design of the assessment.

The assessment regime that proved most successful with this group of learners was:

- A small class test early in the course when some material had been covered. The test was based on review questions provided at the start of the course and was used to confirm that students had kept up with their exercises. The test was designed to give students a measure of their progress sufficiently early in the course to allow them to seek additional help or work harder if required. Only 15% of the course marks were assigned to this test.
- An assignment was an important part of the assessment for this course and provided the students with some choice over the content. For example, some questions in the assignment allowed students to study their favourite aircraft in answering the questions. Providing some choice to the students was another

desirable characteristic of assessment discussed in Section 2.3.5. The assignment also required students to use resources like flight manuals in order to answer the questions. Students were instructed to work on the assignment as individuals and encouraged to seek individual help if they were having problems. The importance of providing students with access to assistance was discussed in Section 3.2.1. The assignment was worth 30% of the course.

- An open-book examination, that contributed the final 55% of the marks for the course, was the final component of the assessment for this course. Making the exam open-book seemed to reduce student anxiety and the tendency to try to guess exam questions and rote learn facts and formulas. The focus of the exam was on allowing students to demonstrate a deeper understanding of aspects of modern avionics systems by using questions that required exploration and explanation. Throughout the course, the aim of the final examination was emphasised to ensure students understood how to succeed in the examination. The students were continually advised that the examination was not based on restating facts or manipulating arithmetic expressions, but rather on students explaining the rationale behind aspects of avionics system design and operation. Examples and case studies similar to those used throughout the course were also used in the examination to give the examination authenticity. For example, during the course, the importance of air data systems was discussed. A suitable air data system case study investigated an aircraft crash in the United States that was caused by groundcrew placing sticky tape over an aircraft's static ports before washing the aircraft and then failing to remove the sticky tape before flight. A corresponding examination question on this case study asked students to explain the sequence of events, the symptoms of the problem, and to explain why air traffic control and the aircrew were so confused that the aircraft eventually crashed. This accident was an example of where a deep and integrated understanding of modern avionics systems may have prevented the accident. It was this sort of deep and integrated understanding that was rewarded by the examination.

6.6 Development of the Course Content

The development of the course content occurred against the structure and learning outcomes developed in the design phase. In developing the content, a number of sources of information were used including existing texts, aircraft flight manuals, and publicly available engineering design reports. I also contacted avionics industry representatives and aviation regulators in Australia and overseas to obtain up-to-date information to assist with content development and its review. These groups were particularly useful in the development of the sections on cockpit displays, aircraft electrical systems, avionics architectures, air data systems and airborne navigation systems. By using industry groups and regulators in this way, I ensured that the course content reflected current best practice and the likely future direction of the avionics industry.

As the content was developed, review questions, case studies and exercises were also developed in order to support student self-learning. This information also assisted in drafting course assessments such as the exam and the assignment discussed earlier.

6.6.1 Development and publication of the Avionics Text

The textbook that was required to support this course needed to provide the breadth and depth of coverage to support the course design, but also needed to be written with a structure consistent with the structure of the flight manuals used by aircrew to study their aircraft. In this way, the book would not only be a suitable resource for the avionics course, but the students could also use the textbook later in their aviation careers as a study companion to their flight manuals.

In developing the course content for the avionics course, a number of texts were used as references. Avionics texts are not as prevalent as texts in other electrical engineering disciplines such as radar. Additionally, because of the broad nature of the term avionics, many textbooks that had *avionics* in their title covered only limited topics or covered the topics in a broad fashion (for example, Cundy and Brown (1997); and Hekfrick (2002)). Another category of avionics textbooks covered a very limited scope but did so in great detail (for example, Nelson (1998); and Titterton and Weston (1997)). A third category of avionics textbooks were marketed as handbooks and consisted of a number of detailed but often unconnected chapters about different aspects of avionics system design (for example, Spitzer (2000) and (2001)). Although many of the textbooks provided useful contributions to the course content, no single textbook reviewed during this process was ideally structured to cover the desired course content to the necessary level of detail.

Comprehensive course notes were drafted and used to support the course for three years. The structure of the course notes reflected the structure illustrated in the mind maps shown in the previous section. Each year, the notes were refined based on student feedback with improvements made in content, referencing and style. In addition to students, avionics industry representatives, aviation regulators, and professional aviators also reviewed the notes and provided valuable feedback that helped ensure that the document was complete, accurate and up-to-date.

The mature notes were submitted to a publisher for consideration and were published in 2007 (Faulconbridge, 2007). An overview of the text is at Appendix C.

Features of the text include:

- Comprehensive references at the end of each chapter in order to support more detailed reading and research by students as required;
- Worked examples and case studies throughout to demonstrate application of avionics theory;
- Use of qualitative techniques (photos, drawings, and simulations) as well as quantitative techniques to explain concepts;
- Inclusion of the underlying physical laws and engineering concepts where relevant to explain the rationale behind avionics system design; and
- Review questions with answers at the end of each chapter to support self-assessment of progress towards the learning objectives.

These features were designed to support different preferred learning styles whilst at the same time helping to promote a deeper understanding of avionics systems.

6.7 Course Delivery

The aims of the course design and delivery were to achieve learning objectives whilst at the same time:

- promoting deeper learning approaches in the students,
- appreciating the nature of adult learners, and
- allowing for learning style diversity.

Some time was spent at the start of the course discussing the different approaches the students could take to learning, and discussing the merits of taking a deeper approach to learning. The discussions helped raise students' awareness of their options and to explain how a deeper approach to learning would be rewarded because of the design of the assessment regime. The benefits associated with discussing learning approaches with adult students were described in Sections 2.3.4, 2.3.5 and 4.2.5.

The teaching style used during the delivery of the course was chosen to accommodate likely variations in learning style within the group. The use of teaching style in this way was discussed in Section 3.2.3.

Other aspects of delivery were used in order to recognise the general characteristics of adult learners and their interest in learning. For example:

- The knowledge structure was explained at the start of the course to help the students understand what they were learning and why.
- Video presentations were used throughout the course to emphasise the link between aircraft functionality (as documented in the knowledge structure) and performance and the role of avionics. Videos had the additional benefit of breaking up presentations and classroom time and adding variety to the course.
- A number of experienced military pilots were invited to give short presentations to the group in the early stages of the course. The guest lecturers were thoroughly briefed on the course content and learning objectives and asked to give examples in their flying careers when avionics systems knowledge had made a difference to their flying. These presentations served to emphasise the importance, relevance, and practical application of avionics system learning. It was made more convincing to the students because military aviators delivered the message. Students commented very positively on how effective the presentations were.
- The course made use of military flight manuals provided by the ADF. These manuals provided case studies and examples from operational aircraft. This made the material more relevant, provided some concrete examples, and also served to familiarise the students with flight manuals therefore preparing them for future learning.
- Real-world examples were used at different times during the course. Air accidents were found to be a very effective type of example to use. By investigating an aircraft accident, it was often possible to link some of the causes back to a lack of systems knowledge on the part of aircrew or other operational personnel such as air traffic control.
- Even though the students were at the beginning of their aviation careers, it was occasionally possible to use their flying experience in the classroom. The students had sufficient flying experience to contribute to the sections on flight controls, cockpit systems, and navigation systems for example. Using adult student experience as a learning resource was discussed in Section 2.1.4.

Student comments on both the content and delivery of the course were collected as part of the standard UNSW teaching quality process. The results of these reviews are contained in Appendix A. When these reviews suggested improvements or changes, they were considered and incorporated. Improvements were also made over time to the course by monitoring student assessment results and noting areas where students had problems. The idea of improving teaching by monitoring student assessment results was discussed in Section 3.2.4. The success of the course and of the avionics system text is discussed in Chapter 8.

6.8 Review

This chapter explored the design, development and delivery of an avionics systems course to groups of adult learners. The avionics systems course was developed in accordance with the teaching and learning philosophies explored in Chapters 2 and 3, and the development framework explained in Chapter 4.

The development of the course was based on an understanding of the learners involved in the avionics systems course and their need for the course. The need and rationale for the course was expanded using mind mapping to relate avionics systems back to the operation and functionality of modern aircraft, which was a meaningful reference for the group of learners. This process led to the development of desired learning outcomes for the course. Constraints imposed on the course delivery were considered and a structure for the course was developed. The chapter concluded with an explanation of aspects of the course delivery that accounted for the diversity in typical groups of adult learners, whilst at the same time promoting deeper approaches to learning.

During the development of the course, a review of available avionics texts to support the course failed to identify a text that was ideally suited to the course and the audience. The lack of a suitable text meant that a set of course materials was developed. Over time, these were refined and further developed and in 2007 published as a text. Whilst the text has only recently been published, both students and aviation professionals have positively reviewed it.

Chapter 7

Application to the Teaching of Systems Engineering

7.1 Introduction

This chapter investigates the application of the literature review (Chapters 2 and 3) and conceptual framework (Chapter 4) to the design, development and delivery of a systems engineering course to groups of technical, adult learners.

For consistency, this chapter uses the same structure used for Chapters 5 and 6, and therefore first investigates the characteristics of the learner and then describes the nature of systems engineering. The need for the learners to learn about systems engineering is then explored before the design, development and delivery of the course is described.

The systems engineering course has been successfully delivered to the target audience since 1999. In addition, the course has been adapted and delivered as a professional development short course to Government and industry audiences, and is also delivered to groups of postgraduate management students. A major outcome of the application of the conceptual framework has been the development and publication of a series of introductory texts on systems engineering (Faulconbridge, 2001); (Faulconbridge and Ryan, 2002) and (2005)) that use the structure, content and style developed for the course. The texts have been successfully sold worldwide since publication.

7.2 About the Learners

7.2.1 Background, Context and Prior Knowledge

The learners were 4th year Bachelor of Electrical Engineering [BE (elec)] undergraduates studying at the ADFA campus of UNSW. Undergraduate study at ADFA is only open to military personnel so all students will graduate as engineering officers in either the Army, RAN or RAAF. Engineering officers are technical officers usually employed in design, development, testing, maintenance or support roles for technical military equipment and systems. As officers, they will also usually command groups of technical tradespeople. The type of equipment and systems that the students will eventually be responsible for depend on their military service. For example, RAAF engineering officers tend to focus on aircraft, RAN engineering officers on warships, and Army engineering officers on ground-based telecommunication and weapon systems.

Another major part of a military engineering officer’s role (regardless of military service) is to acquire new capability and equipment for the military. The Defence acquisition process involves engineers in the development of requirements documentation, tendering processes, contract management, and engineering management. It is this acquisition role that is the focus of the systems engineering course.

Due to the different avenues of entry to undergraduate engineering courses at ADFA, 4th year students can vary in age from early twenties (for students coming to ADFA straight from high-school) through to the thirties (for students who enter a degree program as mature-age students). All of the students are therefore adult students using the definitions discussed in Chapter 2.

Although all of the students were reasonably experienced students with solid electrical engineering backgrounds, they did not have any significant experience or exposure to systems engineering. Those students who had heard of systems engineering often had some confusion and misconceptions due to the diverse use of the term “systems engineering” in modern engineering and IT industries. In terms of the educational continuum illustrated in Figure 2-6, the students were systems engineering novices.

7.2.2 Motivation, Attitudes and Approach

The students who undertook this course were in the last academic session of a standard 4-year technical degree where they had little or no choice over course content, sustained a heavy course workload, and undertook assessments dominated by closed-book examinations. The systems engineering course was a compulsory unit in their final year of study. Section 2.3 discussed the likely effects of this sort of study regime, namely the likelihood of surface learning approaches being adopted by students. Over the 6 years of teaching this course to this group of learners, I observed that their general approach to learning tended to be a surface approach as evidenced by their eagerness to learn lists, definitions, and facts by rote. The students were also focused on the assessment regime and on what they needed to do to pass the course. In addition, the students often appeared to be "academically tired" and brought a resigned ("not more of the same") attitude to the course. Conversely, as a group, they did respond well to topics where some linkage to their future employment was demonstrated. Practical application and examples tended to invigorate the attitude of the group of learners.

Section 2.3.4 discussed the ability of academically capable students to adopt deeper approaches to learning, where this was demonstrated to be a key to success, more readily than less gifted students. Given that the students in this course were in the fourth year of an academically challenging degree program, it was assumed that the students were sufficiently academically capable to adopt a deeper approach to learning, provided the benefits of that approach were made clear to them. A challenge for the course presenter was, therefore, to demonstrate the practical application and importance of the material during delivery in order to promote the adoption of deeper learning approaches by the students.

7.3 Scope and Nature of Systems Engineering

The following section provides a brief outline of the scope and nature of systems engineering. This background information has been drawn from the text written and published to support this systems engineering course (Faulconbridge and Ryan, 2005), other systems engineering text books such as those by Blanchard and Fabrycky (2006) and Stevens et al. (1998), and systems engineering standards (EIA/IS-632, 1994), (IEEE-1220, 2005).

Systems engineering is a rigorous and repeatable process that allows complex and technical problems to be analysed, understood and solved.

Once the problem is understood, systems engineering techniques facilitate the consideration of a wide range of feasible solutions before supporting the selection of the preferred solution. Systems engineering then assists the user to specify the preferred solution to support its design, development, production, construction and introduction into service.

Systems engineering is a life-cycle discipline that considers technical problems and solutions from their identification, through their in-service phase, to their ultimate disposal. By considering lifecycle throughout the process, systems engineering supports the analysis and appreciation of longer-term issues such as supportability and sustainability during the early design stages.

Systems engineering also has an important management role, as it forms the interface between the technical program and the project management functions. Typical systems engineering management functions include test and evaluation, risk management, configuration management, and progress reviews.

Systems engineering uses a well-established problem-solving process based on iterative analysis of the problem, synthesis of the solution, and evaluation of the solution against the original problem.

7.4 The Decision to Develop the Systems Engineering Course

7.4.1 Introduction

The first step in the conceptual framework presented in Chapter 4 is to make the decision to develop a given course. This decision is based on the need for the course and an appreciation of the constraints associated with the design, development and delivery of the course.

7.4.2 The Need for the Systems Engineering Course

The Department of Defence (under the direction of the Federal Government) is responsible for maintaining a level of military capability sufficient to defend the country. When the Department perceives there is an operational shortfall between current levels of capability and desired levels of capability, a capability gap is documented. Capability gaps are prioritised and resources are allocated to the Department to either reduce or eliminate the gap. Enhanced personnel training, recruitment programs or the redevelopment of operating procedures may close capability gaps. Often, however, major capital equipment procurements are required to address capability gaps adequately.

Major capital equipment projects can involve billions of dollars and many years of work before equipment is introduced into service. Recent examples of major capital equipment procurements in the Department of Defence include the RAAF C-17 aircraft project, the Australian Army's Abrams Tank project, and the RAN's Collins Class submarine project. (Images of the equipment associated with these projects are shown in Figure 7-1.)

Figure 7-1. Examples of major Australian Defence capital equipment projects costing billions of dollars. Top right: An Abrams Main Battle Tank. Bottom right: A C-17 Globemaster. Left: A Collins Class Submarine
(Photos courtesy of the Australian Department of Defence)

Engineering officers from the ADF play an integral role in every stage of major procurement projects, extending from the early stages that aim to document capability gaps, through the design and development stages, to the introduction of the equipment into operational service. Engineering officers require technical competence in a given area of practice and they also require an understanding of the engineering process that is followed during a capital equipment project and how that process integrates with broader project management regimes. The engineering process used by the Australian Department of Defence is an applied systems engineering process.

(In addition, large organisations throughout the world rely on tailored systems engineering processes to close capability gaps and to solve complex technical problems.

This enhances the relevance and importance of engineers becoming familiar with systems engineering concepts early in their professional careers.)

The technical competence possessed by engineering officers comes from a combination of formal education and practical work experience in the field. The Department of Defence recognised that formal education in systems engineering processes would assist engineering officers in executing their future roles on major capital equipment projects, and requested that a systems engineering course be developed and provided to undergraduate engineers at ADFA in their final year of study.

This established the need for the systems engineering course and UNSW therefore decided to develop and offer the course to its electrical engineering undergraduates at ADFA. Elements of the systems engineering course have subsequently been incorporated into the other engineering programs at ADFA in more recent years as discussed in Section 8.1.2.

7.4.3 Course Constraints and Opportunities

The course was constrained by time in that it needed to be presented within one academic session of approximately 10 teaching weeks with 4 hours of lecture time available per week. There was little extant systems engineering experience within the student group so it was assumed that the group had no knowledge of systems engineering theory nor its practical application. This defined the starting point for the course. By the end of the course (and following graduation), students would be expected to fill junior project engineering positions on major equipment acquisition projects within the Department of Defence.

The main opportunity associated with the systems engineering course related to how applicable systems engineering was to the future of the students as professional engineers, and how positively the group of learners tended to respond to topics that had demonstrable relevance and practical application. An opportunity therefore existed to motivate deeper learning in the group by establishing and reinforcing the practical application of systems engineering during the course delivery.

Another opportunity was the richness of current and historical case studies that could be used during the course to reinforce the relevance and importance of the subject to the students.

7.4.4 Course History

When this course was first designed and delivered in 1999, no systems engineering course existed at ADFA. The systems engineering course was therefore designed, developed and delivered from first principles using the methodology presented in Chapter 4.

7.5 Course Design

7.5.1 Introduction

Once the need for the course was established and the decision to develop the course was made, the course was designed in accordance with the conceptual framework presented in Chapter 4 and the constraints and opportunities in Section 7.4.3.

The need for the course assisted in the development of the learning context to ensure that the course was meaningful to the adult learners. As discussed in Section 2.1, practical application to future employment (as professional engineers in this case) has been found to be important to adult learners so the learning context for this course was based on the likely future employment of the students as engineers in organisations such as the Department of Defence. The learning context for the course revolved around the way in which organisations such as the Department of Defence could solve complex technical problems using a rigorous, robust and repeatable process based on systems engineering philosophy.

A set of learning objectives was developed from the need and learning context. The need for the course and its context, along with the learning objectives, helped explain to students the rationale behind the course so they could understand why it was important to them and their future careers.

The course structure required to deliver the learning objectives was subsequently developed followed by course content development and delivery.

7.5.2 Course Overview

From the starting point and the constraints set out in Section 7.4 above, the basic level of knowledge needed is as illustrated in the mind map of Figure 7-2.

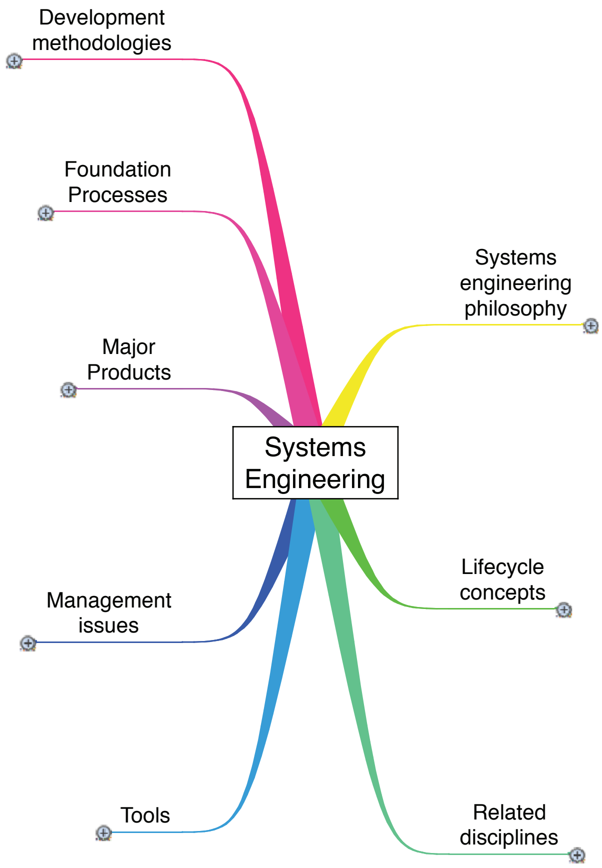

Figure 7-2. A mindmap showing the principal components of systems engineering knowledge

Fundamentally, systems engineering is a philosophy and a way of thinking. Hence it was considered important to provide some background information on the systems engineering philosophy. As systems engineering is essentially complex problem solving, it is possible to engage the group of learners in a discussion about how engineers solve complex technical problems. This sort of discussion helps to engage the group of students and can naturally contain a discussion on the major aspects of systems engineering, as follows:

- Systems engineering activities are usually executed against some type of lifecycle model with each phase of the lifecycle building on the previous phase whilst at the same time looking forward to the succeeding stages. Whilst different lifecycle models exist to suit the peculiarities of different industries, the course needed to provide students with an understanding of lifecycle concepts and exposure to at least some of the most popular lifecycle models used.
- It was also important to ensure that students understood that the success of systems engineering relies on the cooperation and integration of a number of

different technical and non-technical disciplines. Systems engineers rarely work in isolation from specialists in related disciplines.

- There are many tools in existence that help systems engineers to do their jobs. It was considered essential that students were exposed to a cross section of these tools during the course.
- Whilst the students in this course will eventually play a technical role on projects, systems engineering necessarily involves an element of management in order to control and coordinate the technical process. There are many engineering management issues that were considered important to the emerging systems engineer.
- A systems engineering process produces many products. Some systems engineering products are designated as “end products” that enter into service to close capability gaps. Examples of end products are illustrated in Figure 7-1. Other systems engineering products are considered “enabling products” which are produced in order to deliver end products. Examples of enabling products might include plans, specifications and reports. An appreciation of typical end products and enabling products was considered essential.
- Systems engineering iteratively applies a fundamental problem-solving process throughout the system lifecycle. Students need to understand this process and appreciate how the process is applied throughout the lifecycle.
- There are different design and development methodologies that can be employed in order to solve complex technical problems. Different situations and problems tend to suit different approaches to design and development. Students need to be aware of the different options available to them as systems engineers.

From the basic mind map of Figure 7-2, an additional level of detail was developed in order to support the subsequent generation of learning objectives for the systems engineering course. This additional level of detail is shown in Figure 7-3. Each of these more detailed learning requirements helps to provide the learning context and reinforce the rationale for the course, and were used to develop the learning objectives for the systems engineering course.

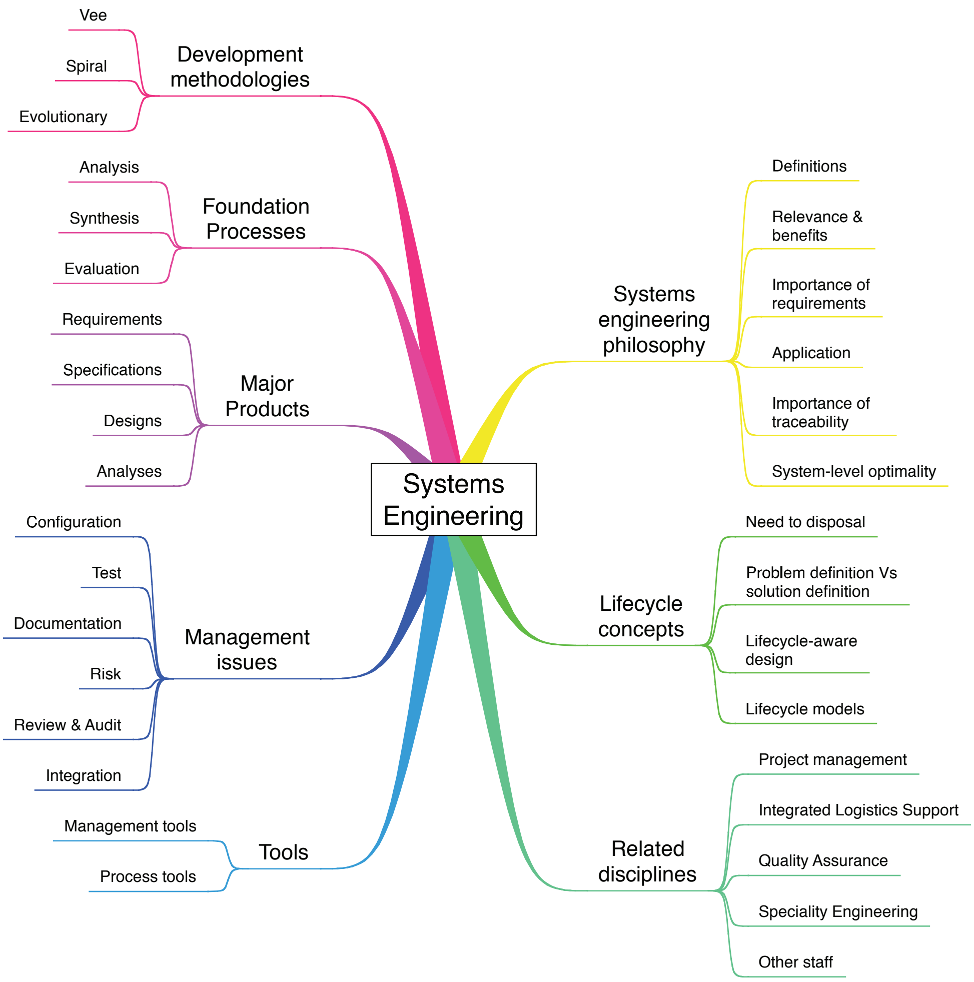

Figure 7-3. The systems engineering knowledge structure with a first level of detail

7.5.3 Learning Objectives

The learning objectives in the systems engineering course were all qualitative. Systems engineering is a philosophical approach to engineering solutions to complex technical problems, rather than a set of quantitative engineering tools. As such, quantitative learning objectives were not applicable to this course.

It was still important that the learning objectives clearly stated what was expected of the students, so accuracy and clarity remained important in writing the learning objectives. For example, at the end of the course, students were required to be able to articulate and explain the systems engineering philosophy of understanding technical problems before developing technical solutions. The students were also required to demonstrate an appreciation of the importance of requirements in the overall systems engineering process.

7.5.4 Development of the Course Structure

Developing the course structure was difficult due to the inter-relationships between the many systems engineering topics that needed to be discussed during the course. Frameworks exist in systems engineering documents such as industry standards (EIA/IS-632, 1994, , AS/NZS15288:2003, 2003, , IEEE-1220, 2005), but these frameworks were aimed at systems engineering practitioners, not systems engineering students.

Whilst working as a professional systems engineer, I formulated and refined a simple model (illustrated in Figure 7-4) to assist me in understanding the many systems engineering topics and their interrelationships. The model was adopted for this course. In addition, it was presented at a systems engineering conference (Faulconbridge and Ryan, 1999), published in a relevant journal (Faulconbridge, 2000), and has been used in other work relating to systems engineering education and accreditation (Kasser, 2000).

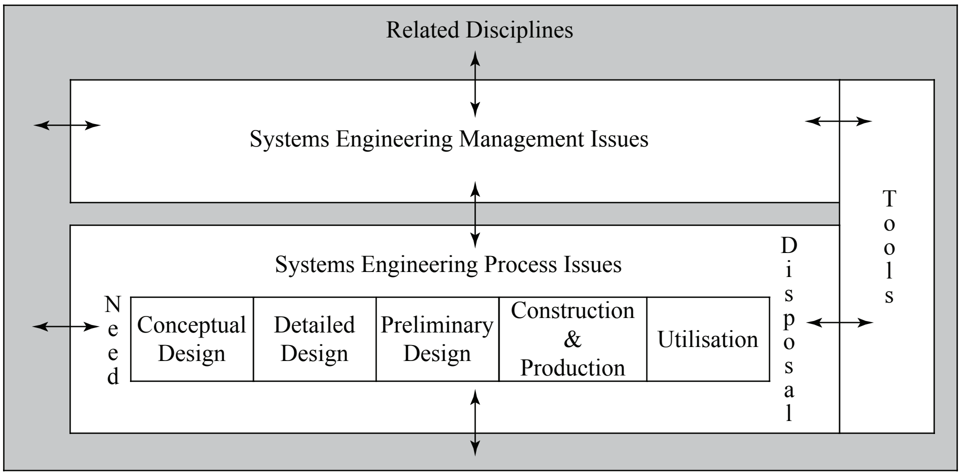

Figure 7-4. Systems engineering educational framework

The structure consists of the following four main sections:

- *Systems Engineering Process*. The systems engineering process occurs throughout a system's lifecycle starting with conceptual design (where the need for a system is established and elaborated) through to the end of utilisation where the system is eventually disposed of. At each stage in the lifecycle, the systems engineering process generates engineering products including specifications, designs and systems.
- *Systems Engineering Management*. The systems engineering management effort monitors, directs, controls and reports on the systems engineering process and products. The management layer (shown in Figure 7-4 sitting above process) is applied consistently throughout the systems engineering lifecycle

and addresses issues such as configuration management, reviews, audits, and testing.

- *Systems Engineering Tools*. There is a range of tools in existence that assist with both systems engineering process and systems engineering management. Tools range from computer-based requirements management systems through to paper-based systems engineering standards. It is important for systems engineers to be aware of the major tools as these help get systems engineering tasks done quickly and effectively.
- *Related Disciplines*. Systems engineering relies heavily on interaction with and cooperation from other professions including project management, integrated logistics support, and quality assurance. Other professions that may be involved include specialised engineering disciplines such as software engineering and hardware engineering. Systems engineering practitioners also interact with non-technical disciplines such as legal practitioners and legislators.

A traceability matrix (Table 7-1) was developed in order to allocate learning objectives to different parts of the course structure. This assisted in the development of the course content, its assessment, and provided students with an understanding of the relationship between the knowledge structure and the course structure.

Table 7-1. Traceability between systems engineering learning objectives and course modules.

	Major Learning Objectives																					
Major Modules	Sys. Engineering philosophy	Fundamental SE process	Relevance and benefits	Define systems engineering	Importance of early effort	Liefcycle focus	Typical lifecycle model	Process through lifecycle	Development methodologies	Requirements management	Characteristics of requirements	Forward/backward traceability	Inter-discipline cooperation	System-level optimality	Systems engineering products	Periodic technical review	Configuration management	Test and evaluation	System integration	Technical risk management	Process tools	Management tools
1. Introduction	■	■	■	■	■	■	■		■	■	■	■	■									
2. Conceptual Design	■	■			■			■		■	■	■		■	■	■	■	■		■	■	
3. Preliminary Design	■	■						■		■				■	■	■	■	■			■	
4. Detailed Design	■	■						■		■				■	■	■	■	■	■		■	
5. Management															■	■	■	■	■	■		■
6. Management Tools																■	■	■				■
7. Process Tools		■								■	■	■									■	
8. Related Disciplines	■												■									

Further information on the structure of the course and the main elements within that structure is at Appendix D.

7.5.5 Development of the Assessment

The assessment used for this course was a combination of written examinations and a major assignment. A number of different assignments topics were trialed in the first years of the course including an assignment based on a fictitious project. After a number of course offers, the assignment that seemed to have the most success, from a student learning and engagement perspective, was that based on the students' individual 4th year engineering projects. (As is the practice in a great majority of 4-year engineering degrees, every 4th year engineering student at UNSW completes such a project as a major part of his or her final year of study, and this project is an opportunity for the student to demonstrate in-depth problem solving and applied research on a unique engineering problem.)

By using their individual projects as the basis of the systems engineering assignment, each student was able to gain first-hand experience of how systems engineering could be applied to a practical problem. This assisted students to understand the need for systems engineering knowledge and provided a motivational context; both of which are important components of the pedagogical model discussed in Section 2.1. In this way, the assignment was viewed as a mean of providing experiential learning for novice practitioners.

In the assignment, students were required to re-analyse their project work and produce specified systems engineering documentation, including concept documents, user requirements, and specifications. Many students reported that doing the systems engineering assignment helped them achieve better results with their 4th year project as they were able to use elements of their systems engineering assignment in their project seminar and dissertation. The fact that the systems engineering products they produced in their assignment proved useful to them helped to reinforce the relevance and benefits of systems engineering. An additional benefit from the institution's perspective was that every student's project was unique, and therefore academic misconduct could be ruled out.

The assignment was not, however, able to adequately examine all of the learning objectives for the course. The written examinations concentrated on learning objectives associated with students demonstrating knowledge of key facts, processes and models. The examinations retained a focus on explanations, where relevant, to reward understanding rather than memorising. For example, the examinations might ask students to describe the systems engineering phases in a standard Department of Defence major project and explain what occurs in those phases and how the phases relate to one another. This is typical of the knowledge and understanding that the graduate engineers will require to engage in conversations, negotiations and engineering evaluations in their future workplaces. A more authentic way of examining this knowledge and understanding may involve fictitious interviews or workplace conversations with each student, but written examinations as described in this section were found to be a pragmatic way of confirming that large groups of learners had met the learning objectives.

7.6 Development of the Course Content

Once the course structure had been determined and the learning objectives assigned, the detailed course content was written. To draft the detailed course content, I started with a systems engineering literature review that I had previously compiled for a coursework subject in my Master of Engineering Science degree. This literature review was augmented by an expanded literature search, and a more detailed review of extant industry and military systems engineering standards. Review and assessment questions were also written for each major module in the course structure during the development of the course content. These helped students to understand the major themes in each module and also showed how the learning objectives could be tested. The review questions also proved useful when setting examinations for the course.

Case studies that could be used during delivery were also identified during this stage. A single worked example based on a commercial aircraft acquisition project was also developed and this was used throughout the course delivery in order to help unify the course content and demonstrate the practical application of systems engineering theory.

7.6.1 Development and Publication of the Systems Engineering Texts

A textbook was considered an important learning resource to ensure students could become active learners in the classroom rather than concentrating on taking notes. Section 2.3.5 discussed the importance of classroom activity in the promotion of deeper learning approaches, and Section 3.2.3 discussed the fact that long periods of note taking in class do not suit any learning style.

A review of possible reference material to support this course revealed that existing texts were pitched at a level for professional systems engineers rather than for students. An example of such a text was an earlier edition of a text written by Blanchard and Fabrycky (2006). Whilst this type of text comprehensively covered the systems engineering discipline for practitioners, I considered it excessive for novice systems engineering students. Another potential source of reference information was from the many existing systems engineering standards, such as the one written by the Electronic Industries Alliance (EIA-632, 1999). Whilst standards provided a framework for systems engineering practice, I considered them lacking in background information and detail to support systems engineering students. Standards were therefore considered systems engineering tools and covered in the relevant section of the course, as illustrated in Figure 7-4.

In the absence of an ideal text, detailed course notes were produced to support the initial offers of the course to allow students to concentrate and participate in classroom discussions rather than taking notes. The content was developed over time and when it had matured, the notes were published as *Systems Engineering Body of Knowledge* (Faulconbridge, 2001). Over 700 copies of this publication were sold.

During subsequent deliveries of the course, a colleague contributed to and lectured on some of the sections relating to systems engineering management and related disciplines (particularly project management). The original text was jointly redeveloped with additional detail in the engineering management and related disciplines sections. Emerging standards and capability maturity models were also added to the original text during this period. The revised version was published as *Managing Complex Technical Projects – A Systems Engineering Approach* (Faulconbridge and Ryan, 2002) and over 1,100 copies of this book were sold. Unfortunately, the publishers of this text priced the book at the professional reference book price point that made it expensive for the undergraduate audience it was designed to support. When copyright reverted to the co-author and me, we decided to publish it locally in order to reduce the price point. Minor amendments were made to the text including updated sections on the standards that had been released or cancelled since 2002. This further revised edition was published as *Engineering a System – Managing Complex Technical Projects* (Faulconbridge and Ryan, 2005) and remains the current version of the work. To date, over 250 copies of this book have been sold.

Significant features of the current text are:

- comprehensive references at the end of each chapter in order to support more detailed reading and research by students as required;
- review questions at the end of each chapter to support self-directed study.
- a continual emphasis on the integrated nature of systems engineering to reinforce the need for many disciplines to solve complex problems successfully;

- a single worked example that reinforces the practical application of the theory and allows readers to follow the systems engineering process through the different chapters; and
- use of drawings and explanations to explain concepts.

The text is dominated by qualitative descriptions of systems engineering concepts and practices in keeping with the nature of the systems engineering discipline. However, quantitative and graphical explanations are also included in the text where possible to provide some support of learning style diversity. The text has been developed around the knowledge structure illustrated in Figure 7-3 and an established educational framework in Figure 7-4. This helps provide the text with an integrated and meaningful structure upon which important systems engineering concepts and facts can be based. The balance between structure and facts (S-F ratio) in course material was discussed in Section 2.3.5 as being important in promoting deeper and longer lasting learning.

7.7 Course Delivery

The aims of the course design and delivery phases were to promote deeper learning approaches in the students, appreciate the nature of adult learners, and allow for learning style diversity.

Some time was spent at the start of the course discussing the merits of taking a deeper approach to learning due to the possible benefits described in Sections 2.3.4, 2.3.5 and 4.2.5. The discussions helped raise students' awareness of their options and to explain how a deeper approach to learning would be rewarded because of the design of the assessment regime.

Section 2.4 discussed the likelihood of learning style diversity in groups of adult learners and recognised the need for an accommodating teaching style to be used during course delivery. Section 3.2.3 discussed ways in which teaching style could be accommodating of learning style diversity. Delivery of a mixture of facts and concepts organised in a clear structure was discussed in Section 3.2.3 as being important for a variety of learning styles. Accordingly, the course structure was communicated to the students in the first lecture of the course and revisited whenever a new topic was presented. In this way, students knew where each content section resides in the structure and how that content related to previous and future sections of the course. The delivery of the course content also made use of a combination of spoken words, diagrams and pictures, and references to written words in order to accommodate different learning styles. For example, case studies were usually presented in the form of class discussions (spoken words) but process discussions were usually based around flow diagrams or illustrations. Students were referred to external reference material in the form of systems engineering standards and templates when applicable. The literature reviewed in Section 3.2.3 also recommended avoiding long lectures requiring extensive note taking. Unfortunately, the timetable for the final year engineering students scheduled systems engineering to be delivered in a single 4-hour block each week during the academic session. The following actions were taken to lessen the adverse consequences of using a single, long lecture:

- the students had access to a text that comprehensively covered the course material (reducing the need for note taking);
- the 4-hour block was structured as 4 shorter periods with a large morning tea break in between the second and third lecture; and
- the short periods involved a mixture of lectures, group discussions, case studies, and worked examples in order to provide the students with some variety and activity.

Other aspects of delivery were used in order to recognise the general characteristics of adult learners and their interest in learning as described by the pedagogical model in Section 2.1. The need for the course, that is the future employment of the students, was introduced in the first lectures and reinforced throughout the course delivery in order to increase the student motivation and their readiness to learn. Because the students did not possess a great deal of relevant (systems engineering) experience that could be drawn upon during the course, I drew on my own experiences gained over 15 years as a professional systems engineer. This helped emphasise the relevance and practical application of systems engineering. In addition to my own experience, I used case studies and examples throughout the delivery to reinforce key concepts.

The main assessment of the course (the assignment) was the subject of ongoing discussion during the course. This helped students focus on the main areas of the course that would help them complete their assignment. The main products of the assignment were based on documentation standards and templates that were used in industry at the time. The students therefore gained experience with industry standards whilst completing their assignment. The assignment was an important part of their systems engineering learning journey.

Another key message that was delivered throughout the course was that the students should consider learning about systems engineering as a life-long journey rather than as a discreet educational activity. This is consistent with Figure 2-6. Students were urged to reflect on the course content and material as they gained relevant professional experience following graduation. This reflection would allow them to develop their own concepts and ideas about systems engineering and to test those concepts continually in accordance with experiential learning models such as those illustrated in Figure 2-2, Figure 2-3, and Figure 2-4.

The course was delivered in a structure that followed the order and content shown in Table 7-1 and in Appendix D.

7.8 Review

This chapter explored the design, development and delivery of a systems engineering course to groups of adult learners in their final year of an electrical engineering degree. The systems engineering course was developed in accordance with the teaching and learning philosophies explored in Chapters 2 and 3, and the development framework explained in Chapter 4.

The development of the course was based on an understanding of the learners undertaking the course and their need for the course. Mind mapping was used to explain the need and rationale for the course and was then used to relate systems engineering to the solution of complex technical problems, which was a meaningful reference for the group of learners. This process led to the development of desired learning outcomes for the course. Constraints imposed on the course delivery were considered and a structure for the course was developed. The chapter concluded with an explanation of aspects of the course delivery that accounted for the unique nature of adult learners, whilst at the same time promoting deeper approaches to learning.

During the development of the course, a review of available systems engineering texts to support the course failed to identify a text that was ideally suited to the course and the audience. The lack of a suitable text meant that a set of course materials was developed. Over time, these were refined and further developed and were published as a series of texts starting in 2001. To date, almost 2000 copies of these texts have been sold worldwide. The success of the course and the course texts are further discussed in Chapter 8.

Chapter 8

Evaluation of the Framework as a Course Design, Development and Delivery Tool

This dissertation has documented aspects of teaching and learning as applied to adult learners and described a conceptual course design framework that can be used to design, develop and deliver a diverse range of technical adult education courses.

The application of the framework to the design and development of three different technical courses and the publication of a number of technical texts was described in Chapters 5, 6, and 7. The courses were delivered using a teaching style and approach based on the information contained in both Chapters 2 and 3.

The aims of this chapter are to discuss:

- the effectiveness of the framework in its development of courses and technical texts for adult learners;
- the effectiveness of the approaches to teaching adult learners adopted as a result of the information contained in Chapters 2 and 3; and
- the flexibility and adaptability of the framework and its ability to be more broadly applied beyond the 3 applications presented in Chapters 5, 6, and 7.

8.1 Application and Success of the Courses and Texts

The effectiveness of the conceptual framework is judged by investigating the success of the three courses and the technical texts developed using the framework. The success of the courses is demonstrated by the continued use of the courses in serving their original purpose, that is the educational need. Even though these courses are compulsory subjects for the students, the providers of the subjects do not have to use the courses discussed in Chapters 5, 6, and 7, but continue to do so despite the existence of other equivalent courses. A further demonstration of success is the expanded application of the courses to provide adult education to different groups of learners. The success of the technical texts is demonstrated by discussing the publication history of the texts and by referring to relevant student and expert reviews.

8.1.1 Radar Systems Course

The radar systems course, described in Chapter 5, was developed using the conceptual framework presented in Chapter 4 and has been run successfully for the RAN since 1999. The longevity and continued demand for the course in its original form provides some measure of its effectiveness as the RAN continues to use this course despite the fact that the radar systems course described in Chapter 5 is not mandated, and that commercial alternatives exist.

In addition to the RAN offer of the course, the course has been:

- adapted to a 3-day commercial short course format and run successfully twice a year since 2001 through the commercial arm of the UNSW at ADFA. The course attracts Defence staff, industry personnel, and employees from other Government agencies.
- adapted and presented each year since 2001 to postgraduate management students at ADFA as part of a technology awareness subject called *Fundamentals of Surveillance Technology* (FST).
- abridged and used by lecturers from the School of Information Technology and Electrical Engineering (ITEE) at ADFA to introduce undergraduate electrical engineers to radar applications in a fourth year elective on radar systems.

- expanded and presented to Electronic Warfare (EW) officers in the RAN and postgraduate students from the Defence Science and Technology Organisation (DSTO).

The increased and ongoing demand for the course, in its various forms, demonstrates that the structure and content is aligned with the needs of industry.

As described in Chapter 5, Radar Fundamentals (Faulconbridge, 2002), has sold more than 1,000 copies worldwide since publication. Apart from supporting the courses described in the preceding paragraph, some of the other known users of the course and the book include:

- The Royal Netherlands Navy uses the text to support training of Dutch naval warfare offices. This is the equivalent course to the Australian course that the text was initially written to support.
- Thales Netherlands (who provided some of the photographic images for the book) purchased copies of the book to assist their marketing people to understand radar systems. They also give the book away as a gift to selected customers as a marketing exercise.
- A provider of professional development training in the United States uses the text to support their basic radar courses that are delivered to management and other non-technical audiences.

8.1.2 Avionics Systems Course

The avionics course presented in Chapter 6 is the newest of the courses that have been developed using the conceptual framework in Chapter 4, and it continues to be used to teach avionics to undergraduate aircrew at ADFA.

In addition to the course presented to undergraduate aircrew, the avionics systems course has also been:

- abridged and presented to aeronautical engineering undergraduates at ADFA as part of a broadening aircraft systems course in their third year of study.
- expanded to include additional technical detail and presented to 4th year electrical engineering undergraduates at ADFA.
- presented to RAAF aircrew and engineers on their Advanced Integrated Systems Course (AISC) run annually by the RAAF.
- developed as a professional development short-course offered annually through the Business Development Office of ADFA. A variation of the short course has

been presented to engineers from Thales Training and Simulation (TTS) Ltd, in order to introduce them to avionics concepts.

The text *Avionics Principles* (Faulconbridge, 2007) was developed from the avionics course described in Chapter 6 and has sold approximately 50 copies since its publication in January 2007. Given its recent publication, it is yet to establish a meaningful publication record. The text has been reviewed by an experienced aviation specialist (Patch, 2007) who found the text to be very suitable for students aspiring to an aviation career. In his review, Patch states that:

> *Ian Faulconbridge has done a masterly job of presenting very complex subject matter in a manner that enables it to be read on two levels—the technical level for those undergraduate and graduate engineers of all disciplines who aspire to understand modern avionics systems in detail, and the systems level for those, such as myself and other aircrew, who need to gain a more practical understanding of the operation of airborne avionics systems and how they contribute to the functionality of modern aircraft. Its presentation in a format that reads more like a Flight Manual enhances its readability for those familiar with this type of document.*

Additionally, a mature draft of the text was used as a course text for *Avionics for Aviators* courses in 2005 and 2006. The 2005 course held at ADFA was subject to student review as part of the UNSW teaching quality framework. A complete list of student comments on the course and the draft text is contained in Appendix A. Although no specific questions on the course text were asked in the review, the following student comments make specific reference to the draft avionics text as a learning resource and help confirm its effectiveness:

The fact that we had course notes/text that followed the information being learnt is excellent.

Information was always relevant and the course text was applicable, in-depth, and followed the course outline – a first in my experience at uni.

Lots of praise for the text. First one I have had which follows what is taught in the course to the letter…a very valuable resource.

8.1.3 Systems Engineering Course

The systems engineering course described in Chapter 7 was developed using the conceptual framework described in Chapter 4 and it has been presented to undergraduate electrical engineers at ADFA since 1999.

In addition to undergraduate electrical engineers, the course has also been:

- summarised and incorporated into project management courses presented to undergraduate mechanical and aeronautical engineers at ADFA.
- expanded with additional worked examples and tutorials to cater for postgraduate management students studying project management at ADFA.
- adapted to a 3-day short course format (becoming the most commercially successful short course run by the Business Development Office at ADFA). This course has been run twice a year since 1999 for general attendance and has also been run as an in-house course for a number of Defence and commercial organisations. Commercial organisations that have requested delivery of the in-house course include Rosebank Engineering Pty Ltd, SAAB Systems Pty Ltd, the RLM Group, and Tenix Corporation. Defence organisations that have regularly used the course since 1999 include the Defence Materiel Organisation (DMO) who often use the course as an introduction to systems engineering for their graduate engineering program, the Land Engineering Agency (LEA), the RAN and the RAAF.
- expanded to include Royal New Zealand Air Force (RNZAF) corporate engineering processes and presented annually to RNZAF personnel as part of their initial engineering officer training. I am currently in the process of negotiating for the course to be run a second time each year for RNZAF procurement agency staff.
- used as the basis of a project requirements management course to be run (from 2008) as part of an MBA program at the University of Southern Queensland (USQ).

The continued growth in demand for the systems engineering course in its various forms demonstrates that the structure, content and delivery of the course continue to meet the needs of industry.

As described in Chapter 7, three systems engineering texts have been published as a result of the development of the systems engineering course. The first text, *Systems Engineering Body of Knowledge* (Faulconbridge, 2001) has sold over 700 copies. This book was expanded and updated before being published as *Managing Complex Technical Projects – A Systems Engineering Approach* (Faulconbridge and Ryan, 2002). Since publication, over 1,100 copies have been sold worldwide. When the copyrights reverted to the authors, the co-author and I decided to update the text and publish it through an Australian publisher (in order to make the book more affordable). This version of the text, *Engineering a System – Managing Complex Technical Projects* (Faulconbridge and Ryan, 2005) has sold more than 250 copies. In total, therefore, almost 2,000 copies of the systems engineering books have been sold worldwide.

8.2 Effectiveness of Teaching Strategies

My approach to teaching has been influenced and refined by the theory and practice discussed in Chapters 2 and 3. Two ways of assessing the effectiveness of a teacher's approach (discussed in Section 3.2) are via student reviews of teacher performance and via critical evaluation by peers.

The validity of measuring the effectiveness of both teaching and courses by using properly collected student reviews was discussed in Section 3.2.4. UNSW uses a process called *Course and Teaching Evaluation and Improvement* (CATEI) (UNSW, 2007) to collect detailed but anonymous student reviews in order to measure both course and teaching effectiveness. The process begins with the relevant Head of School selecting the courses to be evaluated. Administrative staff from the university conduct the review with the class without the lecturer being present. The reviews are collated and processed by the university as part of their commitment to improved teaching and learning. The processed reviews are then forwarded to the lecturer for their information and action as required. Appendix A contains unedited student comments relating to my courses collected by UNSW over an extended period as part of the CATEI process. As stated, I had no control over the courses that were subject to CATEI student reviews and was therefore unable to request that the subjects discussed in Chapters 5, 6, and 7 be subject to detailed student review. Only one set of student comments included at Appendix A directly relates to the courses presented in Chapters 5, 6, and 7. However, all of the comments in Appendix A come from adult learners who were taught by me using teaching approaches developed and refined as a result of the findings in Chapters 2 and 3. This section aims to review the effectiveness of my teaching strategies when teaching adult learners. To that end, I consider all of the student comments relevant to this section of the dissertation as they reflect the effectiveness of the teaching approaches developed as part of this work.

Despite direct requests made by me, student comments and reviews collected by the RAN on the radar course are not made directly available to me. The RAN student comments contain reference to other lecturers and other courses in addition to the radar course. Privacy considerations prevent the RAN from releasing information containing reference to other lecturers to me. Instead, the RAN provides me with general comments and suggestions for improvements when the students raise these. Due to the general and informal nature of these comments, they have not been included here.

Student reviews of commercial courses are also routinely collected by the commercial organisations referenced in Sections 8.1.1, 8.1.2, and 8.1.3 to gauge the effectiveness and value for money they are getting from the courses. As with the comments collected by the RAN, these comments are not made available to me but the continued commercial demand for the courses from these organisations provides some measure of the effectiveness of the courses.

In addition to student reviews, Section 8.2.2 also cites the recent award of a commendation for excellence in classroom teaching as an example of positive peer review of my approaches to teaching.

8.2.1 Student Review

Course delivery was the final stage in the course lifecycle model used in Chapter 4 and its importance in providing an effective learning environment was discussed in Section 4.2.5. Section 4.2.5 also discusses the importance of measuring the effectiveness of the course and its delivery in order to make necessary improvements for subsequent deliveries. The following section explores student comments relating to my approach to teaching adult students, collected at the conclusion of the delivery phase of the course. The intent behind including these comments is not to demonstrate my competence as a lecturer but rather to demonstrate that there is strong correlation between my teaching approaches and the concepts discussed in Chapter 3 as being representative of good teaching practice.

The detailed review responses are at Appendix A to this dissertation, but specific examples have been drawn from Appendix A in order to demonstrate the effective application of the theories of teaching and learning.

Chapter 3 indicates that students want their teachers to be:

- enthusiastic about their role as a teacher,
- interested in their students,
- understanding of the students' situations, and
- helpful when required.

Some examples of student comments that reflect these characteristics in my teaching are repeated below:

On Being Enthusiastic

Lecturer showed enthusiasm for subject.

Lecturer shows a genuine interest in what he is teaching.

Enthusiasm for the material.

On Being Interested

Genuinely interested and knowledgeable.

Interested in students.

He could relate our experiences to his own and adjusted his lecturing accordingly.

On Understanding

Knows the subject matter and understands what the students are going through.

Understood our busy schedule.

Takes into account how tired the class is when teaching.

Empathy – he remembers being a student and does his best to prevent us making his mistakes.

On Being Helpful

Very helpful in areas we had difficulty.

Approachable when we have problems.

Open door policy – was always willing to give up his time to help students.

Chapter 3 also indicates that students want their teachers to:

- be effective communicators,
- possess domain knowledge and experience, and
- have an ability to explain complexity at the students' level.

Some examples of comments that reflect these three areas are repeated below.

On Communication Skills

He was very clear and concise with his communication and his course information was comprehensive and very well laid out.

The information given is generally at a high standard and it is a pleasure to be able to have a lecturer that I can understand, who speaks clear and concise English.

Communication is his big strength.

On Possessing Experience and Knowledge

The lecturer's personal experience enriched the learning

His personal experience added to course to explain importance of subject

He has personal experience which makes him more credible and interesting.

In-depth knowledge by the lecturer

Had good knowledge of the course content, and interesting stories and examples.

On an Ability to Explain Complexity

He explains the subject at our level and doesn't just read off the notes.

Excellent way of explaining difficult concepts in everyday terms

Can explain electrical engineering concepts very well – makes them simple

All subject matter was very well explained

Finally, Chapter 3 indicates that students appreciate courses where:

- the practical application and relevance of the material is explained and reinforced,
- the planning that goes into course structure and timetable allows ample time for learning
- Assessment is fair, reasonable, and aligned to the learning objectives of the course.

Some examples of comments that reflect these three areas are repeated below.

On Relevance and Practical Application

Explained the reasons for learning and structured lessons to make understanding easier.

Excellent examples of what we were studying and how that relates to our careers.
It provided information relevant to my future career.
Relevance to occupation.
Excellent examples of what we were studying, and how it relates to our career.
Interesting topics that are related to our career.
It was relevant to aviators and not aimed at engineers.
Interesting material that related to real life situations.
Everything! Great course, well linked to what we will be doing as part of our job.

On Proceeding at a Reasonable Pace

Material is structured and presented well and at a good pace.
Not too much material for the students to cope.
Willing to work at the speed of the slowest student.
Class times are flexible so if the students need more help on a topic, time is spent on that topic.
Preparation and management of time within the lectures.

On Fair and Aligned Assessment

Class tests were relevant.
In-class assignments are a really good idea, I have learnt a lot from them.
Good fair assessments.

No significant negative comments were received from students when teaching these subjects, however, if received, minor suggestions for improvements were always considered.

8.2.2 Peer Review – Teaching Excellence Award

In 2006, a group of *Avionics for Aviators* students nominated me for a UNSW teaching excellence award. There are no student review comments from these students in Appendix A because the 2006 *Avionics for Aviators* course was not subject to a UNSW CATEI review. Accordingly the nomination by this group of students is considered additional evidence of the effectiveness of my approach to teaching. Following nomination, nominees were invited to submit details of the teaching approaches that they believed contributed to the nomination. The submissions were then reviewed by the Teaching and Learning Committee that consisted of academics from the different academic schools on the campus. I was awarded a Rector's Commendation for Excellence in Class Room Teaching[4] as a result of this process.

8.3 Versatility of the Conceptual Framework

Section 4.1 described the need for the conceptual framework to be sufficiently versatile to cope with major educational variables that may be encountered when designing, developing and delivering different courses to adult learners. By demonstrating a degree of flexibility within the framework, it is reasonable to expect that the framework could be applied to educational developments beyond those already explored in Chapters 5, 6, and 7.

The versatility of the conceptual framework has been demonstrated by its successful application to three different situations (as documented in Chapters 5, 6, and 7). These situations contained significant variation across variables such as course topic, student characteristics, time and constraints. The variation across the three educational situations described in Chapters 5, 6, and 7 is summarised in Table 8-1. Previous sections in this chapter document the effectiveness of the courses developed using the conceptual framework and the resultant technical texts in achieving their educational aims despite these significant variations. It is therefore argued that the conceptual framework presented in Chapter 4 is sufficiently adaptable and flexible to be applied to the development of courses beyond those discussed in Chapters 5, 6, and 7.

The variables summarised in Table 8-1 relate only to the original students and circumstances for which the courses described in Chapters 5, 6, and 7 were designed. One of the measures of effectiveness of the three courses described in Section 8.1 was the expanded application of the original courses to cater for the educational needs of additional groups of learners from commercial and government organisations. The ability of the courses to be refined and adapted to different audiences with different backgrounds and experience levels is further evidence of the flexibility of the design, development and delivery framework.

When a new application for one of the courses in Table 8-1 was proposed, the first step taken was to investigate the educational need of the new application and to identify any differences in the variables outlined in Table 8-1. Generally, the courses were only adapted to situations where the differences in learning need between the original need and the

[4] The Rector's Commendation was awarded by Professor John Baird in his position as the Rector of ADFA at UNSW.

revised need were not great. Differences resulted in some adjustment to the learning objectives, including the addition of new learning objectives, the deletion of unnecessary objectives, and the modification of existing objectives to reflect better the new need. An example of such an adaptation occurred when the radar course was adapted to meet the needs of the FST course (Section 8.1.1). A large number of learning objectives were deleted because the radar component of the course was only one part of the larger surveillance course (other parts included electro-optics, infrared, and lasers). The educational need for the course only required fundamental radar awareness, so more advanced learning objectives associated with radar electronic warfare, for example, were deleted.

Table 8-1. Educational variables in the three courses developed using the framework.

	Courses		
Variables:	**Chapter 5: Radar**	**Chapter 6: Avionics**	**Chapter 7: Systems Engineering**
Nature of the subject	Specific, focused technical subject covering elements of a specific technology.	Broad technical topic covering a range of technologies.	Broad management topic covering general engineering philosophies.
Aim and context	Continuing professional development.	Undergraduate education.	Undergraduate education.
Student educational background	Extremely varied: from high school education to university graduates. Chiefly non-technical.	Reasonably uniform: all students were in their second year of a 3-year BTech (Aviation) degree.	Reasonably uniform: all students were in their fourth year of a 4-year BE degree.
Relevant student experience	High levels of relevant experience within the group of learners. The experience can be considered an important learning resource.	All students have some basic flying experience but none have exposure to integrated avionics systems.	Very little exposure to complex equipment procurements, and little understanding of the processes associated with systems engineering.
Student age and age range	Average student age is approximately mid to late 20s with some older students in their mid 30s.	Most students are around 19-20 years of age with very little variation (1-2 years) across the group.	A wide range of ages, from very early 20s for students coming to university from high school to late 30s for some mature-age students.
Future employment	PWOs in the RAN leading to command.	Operational pilots in the RAN and the RAAF.	Professional engineering officers in the ADF.
Time and other constraints	Restricted course period of 3 working days plus time for an exam. Some access to relevant training aids.	27 contact hours over one academic session with little access to training aids.	40 contact hours over one academic session with no relevant training aids.

Any different constraints on the revised course were also accounted for at this stage. The time allowed for the course, access to learning resources and training aids, and the likely backgrounds of the learners needed to be considered during the revision of the learning objectives.

The knowledge structure of the course generally needed adjustment because the original knowledge structure was developed to establish a meaningful context from the learners' perspective. With new sets of learners, a new context was generally required. Using the FST course as an example again, the learners in the FST course were usually senior Army officers, so the original knowledge structure (developed for RAN warfare officers and based on maritime operations) was not meaningful to the new group of learners.

Changing the knowledge structure, however, did not automatically require a change to the course structure because the course structure was based on the nature of the technical topic, not on the learner's context. However, if there were changes made to the knowledge structure, the relationship between the new knowledge structure and the existing course structure needed to be re-established, as this was used to explain to the learners the rationale and importance behind what was being taught. The relationship (or traceability) between the revised learning objectives and course content was then used to determine the impact of the change on the existing course material. Typical changes to course content (apart from omission of unnecessary detail) usually involved changes to case studies and examples to better reflect the new audience, and the removal of terminology that was peculiar only to the original group of learners.

The delivery of the adapted courses had to be changed to fit in with any new time constraints and venue-specific issues such as access to training aids. However, the general approach to teaching all of the adapted courses has remained relatively unchanged across all of the adaptations discussed in Section 8.1 because all of the adaptations involve adult learners from different backgrounds.

8.4 Conclusions

This chapter discussed the results of the work presented in this dissertation by first detailing the success of the application of the framework to the three courses described in Chapters 5, 6, and 7. This was investigated by outlining the ongoing use of the courses, the adaptation of those courses for additional groups of learners and the commercial success of the courses as professional development courses. The effectiveness of the technical texts that have resulted from the application of the conceptual framework was also discussed. In the case of the radar text and the systems engineering texts, publication history and the use of the books to support similar courses overseas was used as a measure of effectiveness of the texts. In the case of the avionics text that has only recently been published, a published review from an experienced aviation specialist and the review of a class of aviation students were used as measures of effectiveness.

The effectiveness of the teaching strategies and approaches that I have used to teach groups of adult learners was assessed by correlating comments from groups of students collected by UNSW as part of their teaching quality process with the information in Chapter 3. The nomination and award of a Rector's Commendation for Excellence in Classroom Teaching was also cited as an example of peer-reviewed teaching effectiveness.

The versatility of the conceptual framework in designing, developing and delivering technical courses for adult learners was then summarised. The versatility of the framework was seen as important if it was to be applied to course developments beyond those in Chapters 5, 6, and 7. The versatility was demonstrated by the successful application of the framework to three different educational situations that contained significant variation in terms of:

- the technical topic to be taught;
- student age, educational background, experience level, and future employment; and
- educational constraints placed on the course

This Chapter has demonstrated that the conceptual framework is an effective tool to design, develop, and deliver a diverse range of technical adult education courses and technical texts.

Chapter 9

Conclusion

Section 1.2 listed the objectives of this work. This dissertation has documented the achievement of these objectives as follows:

1. *To review existing research and published ideas relating to aspects of adult education and in particular the adult learner.* This objective was achieved in Chapter 2 that explored critical aspects of students and the way they learn, concentrating on adult learners.
2. *To review what attitudes, attributes and approaches are desirable in the teachers of adult learners.* Chapter 3 documented the achievement of this objective by examining elements of current research relating to the characteristics of effective adult teachers.
3. *To document a conceptual framework that was developed and then has been applied to the design, development and delivery of technical education to groups of adult learners.* Chapter 4 documented the conceptual framework that was developed to account for many of the aspects of adult learning explored in Chapters 2 and 3 in order to facilitate the delivery of effective educational experiences for adult learners.
4. *To describe and analyse the practical application of the conceptual framework to three different learning environments.* Chapters 5, 6, and 7 documented the application of the framework to adult technical education in radar systems, avionics systems, and systems engineering. Additionally, Chapters 5, 6, and 7 referred to a body of work published by the author including three technical texts and two co-authored technical texts that have been generated as a direct result of the application of the framework.
5. *To discuss the effectiveness of the framework and the teaching strategies used to deliver technical adult education.* Chapter 8 discussed the effectiveness of

the framework and teaching strategies by investigating the ongoing success of the three courses, the publication record of the published works, and student reviews of teaching effectiveness.

Accordingly, the dissertation has achieved the objectives set out in Section 1.2. The following sections summarise the content of the dissertation, and propose areas of future research that may be undertaken to build on this work.

9.1 Adult Learning

The experience that adult learners bring to educational activities was discussed as an important difference between teaching children and teaching adults. The experience of adult learners may in fact define their learning requirements, and attitudes and motivation towards learning experiences. Experience possessed by adult students should be viewed as an educational resource rather than as a constraint. Various experiential learning models were discussed that highlighted the important roles of concrete experience, observations and reflection, formulation of concepts and the testing of those concepts in real-life. Other differences between adult education and education of children were discussed in Chapter 2. Adults tend to want to understand and appreciate the need for the educational experience before they commit themselves to it. Once committed, however, they tend to become more self-directing than children. They are willing to learn what they see as important to them. The focus of adult learning is on learning that is able to help them in real-life situations. Relevance, therefore, is an important element in adult education.

The fact that students may respond to educational activities in different ways was also discussed in Chapter 2. Two broad approaches that may be adopted by students were discussed; the deep approach to learning and surface learning. Surface learners tend to view educational material as a series of unconnected facts that should be memorised. They consider education as a series of discrete tasks that become a demand on their time. They also tend to respond by memorising facts, words and diagrams in order to succeed.

Learners who adopt a deep approach to learning are more interested in the educational activity and search for meaning within the topics. They tend to use their own experience where possible to relate the current educational activity with previous real-life and educational activities. The deep approach to learning was found to be more likely to result in long term benefit and change in the learner, particularly when dealing with complex and interrelated topics and courses.

The approach to learning adopted by students was seen to be a reaction to an educational situation. It was discussed that learners may modify their approach to learning in response to course design, teaching method and assessment regimes. It is not possible simply to instruct students to adopt a deep approach to learning, but it is possible to encourage a deep approach via appropriate course design (including assessment), and delivery. Deeper approaches to learning are also encouraged by providing learners with a motivational context that emphasises the relevance of the topics they are learning. Encouraging learner activity and interaction during delivery was also discussed as a means of promoting deeper learning approaches in students. Appropriate and aligned assessment regimes coupled with well-structured knowledge bases were also seen as important.

The fact that every adult learner has a unique learning style was discussed in Chapter 2. Whilst it was considered convenient to consider the learning style of the "average student" within a group when designing a course, this was seen as not appropriate, especially in diverse groups of adult learners with different backgrounds and experience. Rather than assume an average learning style, it was seen to be more effective to appreciate the diversity likely in groups of adult learners and to develop an accommodating teaching style during the development and delivery of the course. Appropriate teaching styles included the need to include combinations of facts/data and abstract theories and concepts, to use a combination of presentation styles including written words and visual tools, to use a clear course structure, and use group work and discussions where appropriate. Avoiding long lectures was also found to be important. A learning style model appropriate for students of engineering education was discussed as a way of promoting consistent dialogue and understanding of learning styles between the students and lecturer.

9.2 Teaching Adults

The important role of the teacher of adult students was discussed in Chapter 3. The teacher was seen as a learning facilitator in adult education, responsible for providing students with an opportunity and environment within which to learn. Some of the desirable attributes of teachers of adults were also discussed. The ability of teachers to explain complex concepts in a simple fashion was described as being important in making subjects easily understood and less intimidating to students. An ability to listen accurately to students and a willingness to employ a variety of teaching strategies in order to enhance learning was also discussed. Teachers' attitudes were also discussed in Chapter 3. Having respect for the students and trying to develop some rapport with them was discussed. It was shown to be important to students for their teachers to have not only a genuine interest in the students, but also to have a genuine interest in the subject and in teaching in general. Teachers should also show concern for students' progress and be willing to help students with individual problems. Finally, the importance of teachers striving for continual improvement in their teaching was discussed. The use of student feedback as one of the ways of monitoring teaching quality was also described.

9.3 Conceptual Framework

Chapter 4 detailed a conceptual framework that could be used to design, develop and deliver adult education courses. Many of the ideas from Chapters 2 and 3 were incorporated into the framework so that resultant courses were designed with adult education in mind. The framework revolved around a course lifecycle that started with the decision to develop a course and finished with the ongoing delivery of that course. In between, there was a number of progressive stages in the lifecycle model that saw the course going through design and development stages before being delivered to the adult learners. A well-documented complex problem solving technique involving top-down design and bottom-up development was adapted and incorporated into the framework.

9.4 Application of the Framework

The conceptual framework has been successfully applied to design, develop and deliver three different technical courses to three different groups of adult learners. Chapter 5 described the application of the framework to the design of a radar systems course for groups of non-technical adult learners. A major outcome of this process was the writing and publication of a textbook designed to support adult learning in radar systems. Chapter 6 describes the application of the framework to the design of an avionics systems course that has been developed for groups of student pilots. Again, a text was written and published to support this learning process. Finally, Chapter 7 described how the framework was applied to the development of a systems engineering course for undergraduate engineers in their final year of study. A series of three systems engineering texts have been written and published as a direct result of the application of this framework.

9.5 Results Discussion

Chapter 8 discussed the overall results of the work by first investigating the versatility of the conceptual framework in coping with the educational variables present in the radar, avionics and systems engineering course applications. The variables present in these applications included different topics, different student cohorts and different sets of course constraints. The success of the three courses was described, including details of the growth in the courses' popularity and application since their initial application. The courses continue to be applied to their original need, but have also been used to support additional adult education activities around Australia and overseas in universities, government organisations and the private sector. The success of the publications that have resulted from this work was also described. The publication history of the texts was discussed as a measure of their continued application in the support of adult education. Finally, the effectiveness of the teaching strategies employed as a result of the information in Chapters 2 and 3 was discussed by using student review comments and an example of recent peer review.

9.6 Future Research

As detailed in Chapter 4, the design and development of the radar, avionics and systems engineering courses is ongoing. As reviews and feedback are received, revisions to the courses, their content, and the teaching methods will be incorporated.

Additionally, as new applications for the courses emerge, the courses will go through a similar revision process based on the conceptual framework. Chapter 8 described the process used to adapt the existing courses to new applications. An example of a current adaptation was given in Chapter 8 where the systems engineering course is currently being adapted and applied to the requirements of an MBA program.

Future research could be undertaken to expand, improve and build on the work presented in this dissertation. Three broad areas of future research that may be undertaken include:

- *The application of the framework to the design, development and delivery of online and distance education courses.* The work documented in this dissertation was primarily concerned with the design, development and delivery of courses that were delivered as a series of traditional, face-to-face lectures. The role of the teacher, particularly during the delivery phase of the courses, was found to be critical to the quality of the learning experience. Some of the teaching strategies discussed throughout the dissertation for encouraging deeper learning, accounting for learning style diversity, and leveraging off the experience contained in the group of students, assumed that the course would be delivered face-to-face. Online courses and courses delivered via distance education are alternatives to traditional face-to-face teaching. The role and characteristics of an effective teacher of online and distance education courses may need to be researched. Modifications to the conceptual framework are also likely in order to tailor it to the design, development and delivery of effective online and distance education courses.

- *The application of the framework to the design, development and delivery of non-technical courses.* This dissertation was concerned with the design, development and delivery of technical courses to diverse groups of adult learners. The versatility of the conceptual framework was demonstrated in Chapters 5, 6, and 7 and discussed in Chapter 8. All of the courses discussed in this dissertation were technical courses in engineering disciplines. The nature of the topics being taught and the nature of the adult learners undertaking the courses were important considerations in the design, development and delivery of the courses. The ability of the framework to cater for non-technical courses was not discussed in this dissertation. Non-technical courses, such as those in the humanities and social sciences for example, may require additional considerations to be accounted for during the design, development and delivery phases. Additionally, some aspects of the conceptual framework presented in this dissertation may not be applicable to non-technical courses. Future research may be able to assess the suitability of the conceptual framework and suggest amendments to the framework to make it suitable for the design, development and delivery of non-technical courses.
- *Comparison of the effectiveness of this framework with other design and development frameworks.* This dissertation documented the conceptual framework and then demonstrated its effectiveness in designing, developing and delivering technical courses to diverse groups of adult learners. Future research could aim to discover other frameworks that have been found to be similarly effective and make a comparative evaluation of the frameworks. This research could lead to an improved set of development frameworks suited to different educational circumstances.

- *Preferred learning styles of students choosing an Australian military career.* A majority of the student groups referred to in this dissertation had chosen a career in the Australian Defence Force. Authors such as Kolb (1984) suggest that it may be possible to generalise about student learning styles based on factors such as personality type and career choice. Research could be conducted using undergraduate students from the Australian Defence Force Academy to determine whether there is any discernable difference in learning style preference or learning style diversity in this group of students compared to students from civilian universities. The research could also look for learning style preferences and diversity across students who have chosen a military career but are studying different academic disciplines within the Defence Academy (such as humanities, business, science and engineering for example). This research could be of considerable value to teachers of military students in determining their teaching styles and approaches, especially if a strong learning style preference is evident within this group of learners.

In addition to the ideas for future research presented here, I intend to continue to use the conceptual framework in the future when developing new technical courses. I expect that the framework will continue to evolve and improve as it subjected to additional research, and is applied to future course developments.

Appendix A

Student Reviews of Teaching

The following comments have been collated from 81 student reviews of the author's teaching methods and styles over the period 2003-2006 inclusive. The comments were collected by independent university staff members (without involvement of the lecturer) using the University of New South Wales (UNSW) Course and Teaching Evaluation and Improvement (CATEI) Process. The courses evaluated using the CATEI process were chosen by the relevant Head of School as part of the university's commitment to teaching and learning improvement.

The comments recorded here are direct quotations, and grammatical errors have not been amended. The students whose comments are recorded here include second year and fourth year undergraduates studying towards a Bachelor of Engineering (Electrical), and second year undergraduates studying towards a Bachelor of Technology (Aviation). The comments have been collected in three tables corresponding with the groups of students making the comments.

The comments were collected from responses to the following open-ended questions in the CATEI instrument that related to aspects of the teaching and course that they found to be positive. Accordingly, the comments from each group have been divided into comments about the teaching or teacher, and comments about the course.

The comments recorded in this Appendix about the course were in response to the following questions contained in Form A of the CATEI instrument:

- *3.1 The best features of this course were:*
- *3.2 This course could be improved by:*

The comments recorded in this Appendix about the teaching or teacher were in response to the following questions contained in Form B of the CATEI instrument:

- *3.1 The best features of this lecturer's teaching were:*
- *3.2 This lecturer's teaching could be improved by:*

A.1 Comments from 4th Year Undergraduates (Bachelor of Engineering) studying Avionics

Table 9-1. Comments from 4th year undergraduates (Bachelor of Engineering) relating to either the teacher or teaching.

	Comments
1	Teaching, made it interesting.
2	Relevant, good lecturer
3	The lecturer’s personal experience enriched the learning
4	Very helpful in areas we had difficulty
5	His personal experience added to course to explain importance of subject
6	Genuinely interested and knowledgeable
7	Knowledge, reasonable, not boring.
8	He has personal experience which makes him more credible and interesting.
9	He explains the subject at our level and doesn’t just read off the notes.
10	Enthusiastic
11	Relating the material and the course to real life examples.
12	Ensures we understand what is being taught.
13	The diversity of examples, pictures, videos and past experience that relates to the course material.
14	The information was presented in a manner that it was easy to understand, and interesting.

Table 9-2. Comments from 4th year undergraduates (Bachelor of Engineering) relating to the course

	Comments
1	The course was interesting and applicable, particularly to the RAAF
2	Learnt more about things in this course (such as radar) than I did in the actual radar course[5].
3	It was interesting and applicable to a future air force career.
4	Having handouts were vital for learning
5	Comprehensive notes
6	Some really useful demonstrations too, very good use of the whiteboard.
7	Direct relevance of the material to the ADF, current technology, and applications
8	Very well structured course with a good text.
9	Relevance of material to career.
10	The need to understand the material to do well, instead of just sitting back and cruising along.

[5] Radar was taught as a separate 4th year subject by another lecturer.

A.2 Comments from 2nd Year Undergraduates (Bachelor of Engineering) studying Electronics

Table 9-3. Comments from 2nd year undergraduates (Bachelor of Engineering) relating to either the teacher or teaching. (continued over page)

	Comments
1	His knowledge and guidance on how to complete problems
2	Understood our busy schedule
3	Kept it interesting
4	Fairly interesting
5	Good connection with the students
6	I like his style of teaching
7	Keeps repeating important concepts
8	Approachable when we have problems
9	Interested in students
10	Made learning objectives clear
11	He knows how students think
12	Lectures were structured well and we knew exactly what was expected of us.
13	The lecturers teaching style was excellent
14	The lecturer left nothing to guess work. He spelt it out quite clearly.
15	The information provided was very clear, comprehensive and easy to follow
16	Easy going
17	Teaches you what you need to know
18	Doesn't go off on a tangent talking about things that only the advanced students know
19	Emphasised the relevance of what we were learning and provided useful analogies
20	Logical progression, drawing links to real world examples.
21	Great teaching style – keeps the class interested.
22	Clear in everything, voice, assessments etc.
23	Accepts the subject is boring and makes attempts to interest students.
24	He could relate our experiences to his own and adjusted his lecturing accordingly
25	Excellent way of explaining difficult concepts in everyday terms

26	Easy to understand
27	Preparation and management of time within the lectures
28	Enthusiasm and ability to relate topics to wider engineering applications
29	Open door policy – was always willing to give up his time to help students.
30	He was very clear and concise with his communication and his course information was comprehensive and very well laid out.
31	He kept the class interested in the subject and outlined exactly what was required to gain good results in the course.
32	Teaching style is excellent – good feedback; natural style interactive with students; clear, unambiguous. This makes the learning process much easier.
33	Enthusiastic, knew the subject well and could relate to.
34	Can explain electrical engineering concepts very well – makes them simple
35	Takes into account how tired the class is when teaching
36	Makes electrical engineering subjects enjoyable – don't know how you do it, but I actually look forward to your classes.
37	Good understanding of student needs
38	Explaining ideas and new concepts clearly and slowly so everyone understands
39	Class times are flexible so if the students need more help on a topic, time is spent on that topic
40	Good clear explanations
41	Good structure that adapts to the learning needs of the class
42	Encourages understanding
43	Students can relate to the lecturer
44	Speaks at the correct level for the students
45	Increases generated interest levels through movies etc.
46	Explaining concepts, maintaining interest.
47	Well prepared, good tone, responsive to students
48	Varies lectures, ie uses humour when class is tired, motivating and stimulated my response.
49	The information given is generally at a high standard and it is a pleasure to be able to have a lecturer that I can understand, who speaks clear and concise English.

50	Keeps the students interested and not fall asleep.
51	Good at relating to students learning requirement, ie is able to emphasise to the class the more difficult concepts.
52	Makes sure that everyone understands before moving on.
53	Willing to work at the speed of the slowest student
54	Motivating the students
55	Effective and clear tone.
56	Good pace and patience with students
57	Being prepared and willing to adapt to the changing needs of students
58	Motivational videos excellent!
59	Knows what to expect
60	Excellent at explaining concepts
61	Communication is his big strength.
62	Gives good general advice on becoming an engineer in general
63	Relates to students very well
64	Explains concepts well
65	Teaches relevant material
66	Relates to students well
67	Knows the subject matter and understands what the students are going through
68	Well prepared, course well organised, and very helpful
69	Teaches methods rather than formula-plugging.
70	Empathy – he remembers being a student and does his best to prevent us making his mistakes.

Table 9-4. Comments from 2nd year undergraduates (Bachelor of Engineering) relating to the course

	Comments
1	Course notes were provided
2	Class tests were relevant
3	Good notes
4	Notes were well prepared
5	Practical applications of the theory we learnt in other subjects such as EDL[6].
6	Not too much material for the students to cope
7	It was a follow-on from Electronics 1, and started with a quick recap of Electronics 1.
8	Good course notes
9	Learning how to analyse amplifiers without having to remember complicated formulas
10	Provides excellent material
11	The clear notes and step by step approach
12	Good notes handed out in class
13	Well prepared and good course notes.
14	Has good reference material
15	Good fair assessments
16	In-class assignments are a really good idea, I have learnt a lot from them
17	Material is structured and presented well and at a good pace
18	Well prepared and well presented
19	Well structured topics, good lead in from one topic to another.
20	Clear notes
21	Good, well prepared notes handed out at beginning of session

[6] Electronic Design Laboratory

A.3 Comments from 2nd Year Undergraduates (Bachelor of Technology) studying Avionics

Table 9-5. Comments from 2nd year undergraduates (Bachelor of Technology) relating to either the teacher or teaching. (continued over the page)

	Comments
1	Lecturer showed enthusiasm for subject
2	Lecturer had realistic expectations of the students
3	Lecturer aimed subject at our knowledge level
4	Lecturer made an otherwise dry subject very interesting
5	It was extremely interesting and well taught.
6	The lecturer tailored it to the class needs
7	Excellent examples of what we were studying, and how that relates to our careers.
8	F-111[7] examples awesome
9	Made interesting and not dry
10	In-depth knowledge by the lecturer
11	All subject matter was very well explained
12	Lecturer shows a genuine interest in what he is teaching
13	Explained the reasons for learning and structured the lessons to make understanding easier
14	Taught at our knowledge level
15	Had realistic expectations
16	Had good knowledge of the course content, and interesting stories and examples.
17	Knowledge
18	Down to earth teaching method
19	Reasonable expectations
20	He knew his subject well and conveyed his message very well
21	Enthusiasm for subject matter
22	Understood the students
23	Understood what we wanted to learn about.
24	Relaxed attitude
25	He is very realistic with his teaching style and expectations

[7] The F-111 is a strike aircraft flown by the RAAF.

26	He turned a dry subject into an interesting one
27	Ability to relate to the class
28	Enthusiasm for the material
29	Obvious prior experience
30	Layman's explanations intermixed with facts
31	Interesting, relevant, personal, engaging
32	All subject matter was very well explained
33	Great lecturer who taught in a clear, concise manner and followed the course outline that he laid down at the start of the course.
34	Conveyed enthusiasm well to the class and encouraged comments and participation well

Table 9-6. Comments from 2^{nd} year undergraduates (Bachelor of Technology) relating to the course

	Comments
1	The content was interesting and well-structured.
2	It flowed well and made it easier to understand some topics
3	It provided information relevant to my future career.
4	Relevance to occupation
5	Clear and concise notes
6	Material covered has relevance to program
7	Good introduction to basics without overloading detail.
8	Interesting topics that are relatable to our career.
9	It was relevant to aviators and not aimed at engineers, this is good because it is more intuitive
10	Interesting material that related to real life situations
11	The fact that we had course notes/text that followed the information being learnt is excellent.
12	Information was always relevant and the course text was applicable, in-depth, and followed the course outline – a first in my experience at uni.
13	Well structured notes and course material
14	The fact that we had course notes that followed the information being learnt is excellent.
15	Lots of praise for the text. First one I have had which follows what is taught in the course to the letter…a very valuable resource.
16	Great course, well linked to what we will be doing as part of our job

Appendix B

Overview of the Text "Radar Fundamentals"

The following sections summarise the content of the different chapters and appendices of the text (Faulconbridge, 2002) that has been developed to support non-technical adult learners understanding radar systems using the concepts and philosophies presented in this dissertation.

1 CHAPTER 1 – INTRODUCTION

The introductory chapter explains the very broad concepts of radar system operation including the concept of transmission and reception of electromagnetic energy. A basic block diagram is used. Some fundamental concepts that are needed later in the text are also introduced including the concept of sinusoidal signals. Comparisons are made with the human eye to explain aspects of radar operation. In some regards, radar is superior to the eye (accurate measurement of target attributes [speed, range, bearing, and elevation], the ability to operate over long distances in darkness or in the presence of other visual obscurants). In other cases, the human eye is far superior to radar (resolution, sensitivity, colour vision).

2 CHAPTER 2 – BASIC PULSE RADAR

Pulse radar is the most prevalent operational radar system in existence and uses pulses of electromagnetic energy to measure target attributes. The pulses of electromagnetic energy are characterised by their carrier frequency (operating frequency of the radar), their strength (in terms of peak transmitted power), their width (called pulse width) and the repetition frequency (pulse repetition frequency or PRF). Once students understand these concepts, they are well on the way to appreciating how radar can measure range. They also understand the potential problems with pulse radar including range resolution, ambiguity, and blindness. Resolution, ambiguity and blindness are key performance parameters of operational radar, and students need to know how these performance parameters are directly related to the console settings they choose for the radar. They also need to understand the unavoidable tradeoffs in radar performance to allow them to make the correct decisions during operations. For example, pulse radar can operate with very narrow pulse widths giving exceptional range resolution. These radars lack the energy, however, to operate over long ranges. Operators need to make a trade-off between short range/high resolution and long range/poor resolution.

3 CHAPTER 3 – BASIC RADAR ANTENNAS

The radar's antenna is the interface between the radar system and its natural environment. Antennas are described in terms of their radiation pattern (including main lobe radiation and sidelobe radiation). The relationship between main lobe beamwidth and angular resolution is described to emphasise another important performance parameter of operational radar systems. Some very simple rules of thumb are developed for calculating the rough beamwidth (and therefore likely angular resolution) of radars by observing the size and shape of their antennas and knowing the frequency of operation. Sidelobes are discussed qualitatively. Sidelobe radiation is of central importance to military radar systems (and to a lessor degree to civilian radar systems). Sidelobe radiation can expose fuel, ordnance and personnel to the very real risk of non-ionising radiation (even when the antenna appears to be pointing away). From an electronic warfare perspective, sidelobes are exploited by adversaries in both electronic support and electronic attack. Sidelobes can also create problems with co-located electronic equipment.

Whilst discussing antennas, students are also introduced to the concept of electromagnetic polarisation and why it is important to radar system design and operation. Linear and circular polarisation are described as are the situations in which the different polarisation options might be used. Examples like periscope detection using vertical polarisation and detection in poor weather using circular polarisation are used.

Although students do not necessarily appreciate the real meaning of the measure, they are also introduced to the concept of antenna gain as a measure of the antenna's ability to concentrate electromagnetic energy in the direction of the target. A simple expression is developed taking into account radar operating frequency, antenna dimensions and antenna efficiency. The rationale for learning about antenna gain becomes clear in Chapter 5 of the book, which deals with the calculation of the maximum range of radar systems.

4 CHAPTER 4 – RADAR DISPLAYS AND INTERFACES

In some older systems that are still in service, radar systems drive dedicated operator displays. Some classic radar displays are described. In most modern systems, however, radar is simply one part of a much larger surveillance capability and operator displays are generally a ‘fused’ representation of the physical situation as observed by a number of sensors. This chapter looks at three broad operational arrangements showing the role (or context) of radar in the broader surveillance task. The three arrangements include a naval warship, a military aircraft, and a modern air traffic control system.

5 CHAPTER 5 – RADAR RANGE EQUATION

Radar operators and analysts need to be able to predict likely radar performance under a variety of conditions. The key question asked by operators generally relates to the range at which a given radar system is likely to detect a given target type. Clearly, this depends on a number of radar, target and environmental conditions including:

- Radar transmitter characteristics such as frequency of operation, pulse width, pulse repetition frequency, and peak transmitted power;
- Radar receiver characteristics that determine sensitivity such as noise figure and required signal to noise ratio (SNR);
- Antenna characteristics such as beamwidth, gain, and rotation/revisit rate;
- Target size as seen by the radar (called radar cross section or RCS); and
- Environmental considerations such as rainfall rates and atmospheric attenuation.

Chapter 5 gradually introduces students to the concept of the radar range equation by ‘walking’ through a detection scenario and building the radar range equation from first principles. This allows students to stop at any point in the process and ask for clarification before proceeding. At the end of the process, a reasonably comprehensive radar range equation has been derived which allows a detection scenario to be investigated using basic arithmetic skills (and a scientific calculator).

The information needed to understand the range equation has been provided in the previous chapters, so Chapter 5 is merely pulling the information together. At the end of Chapter 5, students are able to discuss critical operational tradeoffs in radar performance with the information they have gained. For example, reducing the transmitted pulse width of a pulse radar improves range resolution and reduces the minimum range of the radar, but has an adverse effect on the maximum range of the radar.

6 CHAPTER 6 – CONTINUOUS WAVE RADAR

Chapter 6 is dedicated to continuous wave (CW) radar techniques and introduces a very important concept called the Doppler effect. Students are therefore introduced to CW radar in this chapter but arguably more importantly, they also learn that radar techniques can be used to provide an instantaneous measurement of target speed.

The concepts of operation and strengths and weaknesses of CW radar are discussed and related to common CW applications like tracking and illumination radar.

7 CHAPTER 7 – FREQUENCY MODULATED CONTINUOUS WAVE RADAR

Unmodulated CW discussed in the previous chapter cannot measure range to a target. The discussion of CW is therefore extended to cover a well-known technique whereby frequency modulation is added to the CW carrier to allow the radar to measure target range (as well as speed and angle). An example of this type of radar is used to explain how these measurements are made.

Popular applications such as navigation radar and airborne radar altimeters are discussed.

8 CHAPTER 8 – PULSE DOPPLER RADAR

By building on the previous discussions of pulse radar techniques (in Chapters 2 and 5) and the concept of Doppler theory in Chapters 6 and 7, the ideas of pulse Doppler radar are a logical transition. Modern pulse radar systems will generally make at least some use of Doppler techniques so it is important that students understand the concepts. Most importantly, Doppler allows modern radar to discriminate between slow moving and stationary targets and potentially lethal fast moving contacts. This represents another form of radar discrimination and may allow the radar to determine how many targets are present (even if they are within the resolution cell of the radar). Additionally, the more capable pulse Doppler radars can perform rudimentary target classification by investigating the Doppler spectrum in more detail. For example, some modern radars are able to alert operators that the contact is a helicopter versus a fixed wing aircraft by identifying the characteristic Doppler signature of a helicopter fuselage mixed with the Doppler signature of the main and tail rotors and rotor hub. In some cases, it may be possible to determine the type of helicopter if helicopters’ signatures are known.

Whenever radar performs measurements like speed measurement (derived from Doppler information), there will be errors and ambiguities. Arguably, the most famous in pulse Doppler radar is called Doppler blindness. This occurs when a target travels at a speed that creates a Doppler shift of a multiple of the radar’s pulse repetition frequency (PRF). Essentially, it is a form of aliasing (in the signal processing sense of the term). Operators must understand ambiguity and errors in radar measurement, and these are introduced in this chapter.

9 CHAPTER 9 – TRACKING RADAR TECHNIQUES

Techniques exist for radars to track their targets in angle. These radars can be dedicated tracking radars as found on some warships, or multi-mode radar systems may have a tracking function or mode. Tracking techniques each have their advantages and disadvantages, strengths and weaknesses. This chapter discusses some of the major techniques used by modern radar systems including sequential lobing, conical scanning, and monopulse techniques. A brief discussion on range tracking involving the use of split range gates is also included. The problems associated with targets that ‘glint’ or rapidly change radar cross section are described as are techniques like range gate pull off (RGPO) and velocity gate pull off (VGPO).

10 CHAPTER 10 – PULSE COMPRESSION

Pulse compression is a radar technique that uses signal processing to allow radar to enjoy most of the benefits of extremely narrow pulse widths whilst keeping within peak power limitations of the transmitter. It works by employing broad transmitted pulses that contain significant bandwidth by virtue of modulation within the pulse. The receiver employs a matched filter to detect the presence of any signals containing the transmitted modulation. The net effect of this process is equivalent to the radar transmitting an extremely powerful, narrow pulse. To non-technical students, this is a very difficult process to grasp, so this chapter uses simulations to show the results of the process.

The effect of pulse compression on range resolution is discussed and simulated. The radar range equation is revised to include the impact of pulse compression on radar range. Some of the problems associated with pulse compression such as 'range sidelobes' caused by signal processing are discussed and contrasted with the other sidelobes (antenna sidelobes) with which the student is familiar. The impact of target Doppler is also described.

11 CHAPTER 11 – SYNTHETIC APERTURE RADAR

From the chapter on radar antennas, students know that very large radar antennas produce very narrow radiation beamwidths that, in turn, provide excellent angular resolution. Synthetic aperture techniques allow radars with small antennas to synthesise large effective apertures over a finite period of time by exploiting relative motion between the radar and the target. This chapter investigates the concept of synthetic aperture radar (SAR) and inverse synthetic aperture radar (ISAR) and details the factors that impact on the maximum effective length of synthetic apertures and their corresponding angular resolution. Some of the problems associated with SAR and ISAR are also described to ensure students do not get the impression that SAR and ISAR are without tradeoffs.

12 CHAPTER 12 – SECONDARY SURVEILLANCE RADAR

Secondary surveillance radar (SSR) is more of a communication system than a radar system but is included in the text for completeness. SSR relies on cooperation between the interrogator (the radar system) and the interrogatee (the target). The radar transmits an encoded signal towards the target requesting information such as identity and altitude. The target is equipped with a transponder that interprets the encoded signal and transmits an encoded response. This information is often correlated with primary radar information before being used by radar operators.

13 CHAPTER 13 – THE NATURAL ENVIRONMENT

The natural environment has a drastic impact on the performance of radar system and students need to appreciate this as it is often the difference between theory and reality from a radar perspective. Topics covered in this chapter include the impact of radar reflections from the earth’s surface, refraction of radar’s electromagnetic energy as it passes through the atmosphere, attenuation of the radar’s energy by the earth’s atmosphere, and the presence of noise in the operating environment.

At the end of the chapter, students should appreciate concepts like multipath effect and the likely impact this effect has on radar functions like low altitude tracking. The students should also understand why the radar’s horizon is slightly longer than the optical horizon. The concept of ducting is also described in this chapter. The likely attenuation of radar energy as a function of frequency is described and quantified as is the attenuation of energy due to rain. The students should now appreciate why long-range radars must operate at low frequency. Finally, the classical categories of noise as they apply to radar systems are discussed.

14 CHAPTER 14 – CLUTTER

Radar energy is reflected back towards the radar from a range of sources, not just targets of interest. Radar receivers need to be able to discriminate the returns from targets from the other reflected energy. Radar returns from non-targets is called ‘clutter’ as it clutters the radar receiver and display and makes detection more difficult. Classic sources of clutter include the earth's surface and the ocean surface. This chapter details the nature of clutter and describes how to quantify the problem via the concept of clutter radar cross section density. By quantifying the problem, students can then see how best to maximise the so-called signal to clutter ratio with a view to successful detection. At this stage, students are limited to looking at reducing the area of clutter illuminated by the radar's transmission. In the next chapter, they look at what role receivers play in the solution of the clutter problem.

15 CHAPTER 15 – RADAR RECEIVER TECHNIQUES

The previous chapter described why detection is sometimes difficult which leads nicely into some specific techniques commonly employed by radar receivers. Students who have operated radar systems are familiar with acronyms like STC (sensitivity time control), FTC (fast time constant), and IAGC (instantaneous automatic gain control). This chapter attempts to describe qualitatively what these techniques are and how they help with target detection in clutter. At the end of the chapter, students should be able to describe the techniques and how they assist in minimising the clutter problem.

16 CHAPTER 16 – ELECTRONIC SUPPORT

Electronic support (ES) is considered to be the 'eyes and ears' of electronic warfare. From a radar perspective, ES aims to detect, locate and identify enemy radar transmissions. From previous chapters, this clearly relies on the transmission characteristics (of the enemy radar) but also the ES characteristics including the receiving antenna and receiver. This chapter also describes the very important concept in ES called probability of intercept (PoI) that looks at the detection scenario and develops an appreciation of how successful ES efforts are likely to be. As is often the case, this appreciation demonstrates how ES systems can be designed to maximise PoI. Successful ES provides operators with information on enemy radars including their presence, lethality, and location. This information is used to inform tactical decision-making.

17 CHAPTER 17 – ELECTRONIC ATTACK

Once an enemy radar has been detected, identified and located, options open to operational people include electronic attack (EA). EA can take one of many forms but always involves interfering in some way with the enemy radar’s receiver. For example, chaff (usually small slithers of aluminium or other conducting material) can be deposited in the air to reflect large quantities of radar energy back towards the radar receiver. Depending on how chaff is employed, it may conceal aircraft and ships from enemy radar, or may create multiple (false) targets on the enemy’s radar. Another example of EA is called jamming. Jamming involves carrying a transmitter and antenna capable of replicating the enemy radar’s transmission. By controlling the time and strength of the jamming, EA can interfere with enemy radar with a view to either deceiving or saturating the enemy radar system.

This chapter revisits the radar range equation introduced earlier to investigate the likely effectiveness of radar jamming under different circumstances. This leads to the concept of ‘burnthrough’, which is the range at which radar power is able to burn through the jammer’s power making it ineffective. Burnthrough is important to both radar operators and platforms trying the jam the radar. The radar generally detects targets within the burnthrough range, so radar operators and designers try to make burnthrough as large as possible. Targets outside burnthrough are generally not detected so EW platform operators and jammer designers try to make burnthrough range as small as possible.

18 CHAPTER 18 – ELECTRONIC PROTECTION

Electronic protection (EP) aims to protect radar systems from enemy ES and EA. Once ES and EA are understood, electronic protection becomes very straightforward. By revising the concepts described in the preceding two chapters and discussing the issues from the radar’s perspective (as opposed to the EW operator’s perspective) it is possible to investigate EP. EP measures can be built into all of the components of a radar system. Accordingly it is a neat topic to have at the end of the text as it draws on a lot of the material in the preceding work. Antennas with low sidelobes, active cancellation and variable polarisation provide a measure of EP. Transmitters that produce encoded transmissions, use variable transmission frequencies, and alter transmission timings, also provide EP. Receivers using techniques described in relevant chapters also assist.

19 APPENDICES

Non-technical audiences are often confused by the engineers' use of decibels in lieu of linear units and ratios. One of the appendices explains how to translate to and from decibels to assist students who are not comfortable with decibels. The Greek alphabet is another tool often taken for granted when dealing with technical students. Non-technical students can struggle with the extensive use of the Greek alphabet in engineering formulas. The upper and lower case Greek alphabet is included to help these readers. Finally, standard engineering prefixes are explained and expanded to assist non-technical students to read and understand the text.

Appendix C

Overview of the Text “Avionics Principles”

The following sections summarise the content of the different chapters and appendices of the text (Faulconbridge, 2007) that has been developed to support non-technical adult learners understanding avionics systems using the concepts and philosophies presented in this dissertation.

1 CHAPTER 1 - INTRODUCTION

The aim of Chapter 1 is to place the many systems found in a modern aircraft into context so that the reader understands the system makeup of a modern aircraft, and understands where avionics fits into the broader context.

An aircraft is designed with core functionality in mind. It may be a transport aircraft, a fighter aircraft, or a commercial aircraft. In addition to core functionality, all aircraft need to be able to communicate, navigate, and identify themselves. This chapter explores the set of functionality found in a typical aircraft and then describes the complex systems found in a modern aircraft such as airframe, hydraulics, pneumatics, flight controls, and avionics.

The history and future of avionics development is then discussed followed by a more detailed summary of major avionics components.

2 CHAPTER 2 – AIRCRAFT ELECTRICAL SYSTEMS

Avionics systems consume a variety of electrical power including AC power of different voltages and frequencies and DC power of various levels. The generation, conditioning, and distribution of electrical power is performed by the aircraft electrical system.

This chapter investigates the major electrical components found in a typical aircraft electrical system and discusses the standard set of electrical outputs required from an electrical system. The design principles adopted by the designers of aircraft electrical systems are then discussed followed by a look at the likely future of aircraft electrical systems emerging in the next generation of commercial and military aircraft.

3 CHAPTER 3 – FLIGHT-CONTROL SYSTEMS

Modern commercial aircraft are designed with fuel efficiency in mind, whilst agility and stealth considerations are driving the design of modern military aircraft. The resultant designs may require stability augmentation to enhance passenger comfort in the case of commercial aircraft or stability in the case of military aircraft. Stability augmentation is one function provided by fast-acting avionics computer system called the (digital) flight control system. In additional to stability augmentation, mundane flying tasks such as holding a certain heading or altitude are also often performed by the flight control system.

In the past, the pilot controls in the cockpit were either directly connected to the relevant aircraft flight control surface, or connected to a hydraulic actuator responsible for driving the control surface. In most modern aircraft (both military and commercial), it is more likely that there is no direct connection between the pilot's controls and the control surface. Instead, a system known as a fly-by-wire system may be employed. In this sort of system, the pilot's controls are connected to a computer system and the computer system drives the control surfaces (via hydraulic or electro-mechanical actuators). This chapter explores the many design issues associated with fly-by-wire systems.

4 CHAPTER 4 – AIR-DATA SENSORS

Air-data sensors measure the static and total pressure that the atmosphere is exerting on the aircraft and converts this basic data into a range of more detailed information including airspeeds and altitudes. The information provided by air-data systems is some of the fundamental and most important data provided by aircraft sensors.

This chapter introduces the relevant laws of physics and basic assumptions made by aircraft air-data systems in calculating the derived information. The chapter provides readers with a worked example and a series of ‘shortcuts’ to allow rapid calculation of the derived information from the fundamental air-data measurements.

The chapter also describes the information provided by a typical air-data system and how that information is used by the pilots in the cockpit and by other avionics systems such as flight control systems.

5 CHAPTER 5 – INERTIAL SENSORS

Aircraft navigation systems and their pilots must know where they are and what their orientation is in space relative to some point of reference. The earth’s centre is a common point of reference in aircraft systems. Inertial sensors are able to provide this information to the aircraft by measuring linear accelerations (using accelerometers) and rotational accelerations (using gyroscopes). Aircraft attitude (in terms of roll, pitch, and yaw), angular accelerations (in terms of roll rate, pitch rate, and yaw rate), and linear accelerations (in terms of forward, sideslip, and vertical accelerations) provided by the inertial sensors are used in the cockpit but also by a plethora of avionics systems including flight control systems and navigation systems.

This chapter introduces the reader to the basics of gyroscopes and accelerometers and then discusses mechanical gyroscopes and optical gyroscopes. Again, the relevant laws of physics are introduced and reinforced using worked examples.

6 CHAPTER 6 – RADAR SENSORS

Radar is an electromagnetic system that is able to provide a host of information to the aircraft and its aircrew. The basics of radar operation are covered in this chapter before concentrating on airborne applications. The basics include how radars detect targets before measuring target information such as range, speed, bearing and elevation. Some of the ambiguities and errors associated with radar operation are covered in this chapter also.

Airborne-specific radar topics including radar altimeters and airborne pulse Doppler techniques are covered, in addition to standard radar fundamentals. This section emphasises some of the problems associated with radar operation that are peculiar to airborne applications.

The mathematical basis of radar operation is also discussed, and a worked example is used to reinforce the theory. As with all worked examples in the book, the worked example is based on an operational radar system in service throughout the world.

7 CHAPTER 7 – ELECTRO-OPTICAL SENSORS

Electro-optical sensors make use of energy within the optical portion of the electromagnetic spectrum. On aircraft, typical electro-optical sensors include infrared systems, lasers, and TV systems. This section introduces the reader to the relevant laws of physics to develop a core set of tools that enable the calculation of likely sensor performance from first principles. The theory of operation of electro-optical sensors is investigated, the major components of electro-optical sensors are described, and methods used for searching for and tracking targets are investigated.

As with the other chapters, an operational electro-optical system is used as the basis of a worked example to help reinforce the theory discussed in the chapter.

8 CHAPTER 8 – COMMUNICATION SYSTEMS

Aircraft and aircrew must be able to communicate with entities on the ground and in the air. This communication may involve voice communication but it can also include data communication. This chapter covers the fundamentals of analogue and digital communication systems as they apply to aviation. Concepts such as modulation (including FM, AM, and PM) are described, as are their digital equivalents (FSK, ASK, and PSK). The different bands within the electromagnetic spectrum used for communication (UHF, VHF, and HF) are also defined. A basic block diagram is proposed and discussed to give the readers an understanding of the major elements in a typical communication system.

Data communication is also critical to modern aircraft as wide area networks are formed between aircraft and elements on the ground. The military tactical data link called

Link 16 is used as the basis of a case study to explain the concepts of wide-area data communication as it applies to the modern military aircraft.

9 CHAPTER 9 – NAVIGATION SYSTEMS

A pilot of the famous SR-71 reconnaissance aircraft (that flies at over 3 times the speed of sound) was quoted recently as saying that “*you have never been lost until you have been lost at Mach 3!*” His statement indicates how important navigation is to aircraft, especially fixed-wing aircraft where it is not always possible to land and ask directions. Airborne navigation tends to use one of two main methods; dead reckoning or reference to external systems.

Dead reckoning navigation uses the aircraft’s starting point and its displacement over time to determine current location. Dead reckoning relies heavily on the information provided by aircraft sensors such as radar, electro-optical sensors, and inertial sensors.

Referencing external systems at known locations either in space or on the earth’s surface allows airborne navigation systems to calculate the aircraft’s current location. Common navigation aids include VHF omni-directional range (VOR), distance-measuring equipment (DME), tactical air navigation (TACAN), and global positioning system (GPS).

This chapter also includes a discussion of the system used to assist the aircraft in the final stages of its flight; landing. Systems like the instrument landing system (ILS) are described to provide the reader with an appreciation of the theory of operation.

10 CHAPTER 10 – AVIONICS ARCHITECTURES

Modern avionics systems are essentially a series of networked computers each performing a defined range of functions. Avionics architectures incorporate the design of the avionics system and the design of the underlying data networks. Avionics architectures have evolved over many years from first generation architectures to fourth generation architectures that will be present in some of the military and commercial aircraft currently under development. The history of avionics architectures is discussed in this chapter leading to a discussion of the most prevalent network technologies in the current generation of avionics systems.

The case study in this chapter is based on a famous military data-bus standard called MIL-STD-1553B (1978). All aspects of this standard are described to provide readers with an insight into how typical avionics architectures are formed.

11 CHAPTER 11 – AVIONICS SOFTWARE

The software running on the avionics computers often defines the functionality of modern avionics systems. Avionics software is an example of real-time software. Real-time software is software where execution time is of critical importance. An example of this is the software running on the flight control computers on-board aircraft. In some highly agile aircraft, the equations of motion of the aircraft must be solved up to 100 times a second. Naturally, time constraints place additional demand on the computational hardware but also impact on the design and development of avionics software.

This chapter introduces readers to the concept of real-time software and the need to schedule software tasks during the design and development of the software. Scheduling options are described in this chapter and a scheduling mechanism called rate-monotonic scheduling is used as the basis of a case study. The case study is used to highlight some potential problems and possible solutions in a realistic scenario.

12 CHAPTER 12 – COCKPIT SYSTEMS

The cockpit is the user interface in an aircraft. The design and layout of the cockpit is critical to how effectively the pilot and aircraft interact. This chapter details some of the fundamental considerations accounted for when a cockpit is designed. The technologies used in the modern cockpit are covered in the chapter including a discussion on the use of displays, audio, and hands-on controls.

An increasingly important system employed in the cockpit is image intensification often in the form of night vision goggles (NVG). Although really a sensor, NVG theories and concepts are covered in this chapter. Head up displays (HUDs) and helmet-mounted displays (HMDs) are also described.

13 APPENDICES

The appendices are used to help readers to understand the material in the book without having to refer to external material. Appendix A is a comprehensive list of acronyms and their meaning, Appendix B is an explanation of the military equipment designation system (a very useful resource for those involved in either military or civilian aviation), and Appendix C includes the Greek alphabet and common engineering prefixes.

Appendix D

Overview of the Texts relating to Systems Engineering

The following sections summarise the content of the different chapters and appendices of the latest text (Faulconbridge and Ryan, 2005) that has been developed to support non-technical adult learners understanding systems engineering using the concepts and philosophies presented in this dissertation. This text has evolved from earlier texts written to support systems engineering education (Faulconbridge, 2001), (Faulconbridge and Ryan, 2002).

1 CHAPTER 1 – INTRODUCTION TO SYSTEMS ENGINEERING

Chapter 1 introduces the reader to the definitions of systems engineering and the history associated with the discipline. Both definitions and history are vitally important due to the confusion associated with the extensive use of terms such as ‘engineering’ and ‘systems engineering’.

A lifecycle model is introduced to ensure readers understand what a lifecycle is and how it is used in a complex system development. The lifecycle used is based on popular lifecycle models to ensure readers are able to assimilate their understanding in different practical situations.

The underlying systems engineering process involving analysis, synthesis and evaluation is introduced and explained. This process is applied iteratively throughout the remainder of the text.

The framework for the remainder of the text is introduced in Chapter 1. The framework for the text is based on an educational framework that has been found to be effective in educating diverse groups of adult learners in systems engineering (Faulconbridge, 2000) and (Faulconbridge and Ryan, 1999).

2 CHAPTER 2 – CONCEPTUAL DESIGN

Conceptual design is arguably the most critical of the lifecycle stages as it is the period during which the problem is identified, defined and documented. During this period, the 'owner' of the problem recognises their problem and begins to analyse their requirements for the solution. The requirements are focused on defining what the solution needs to do to solve the problem, how well the solution needs to perform, under what conditions the performance is required and what other systems are involved in the solution's successful operation.

Once the problem is understood, the relevant industry is generally involved in proposing broad solutions to the problem. These solutions will vary in terms of cost and in terms of compliance against the requirements. The owner of the problem (usually called the customer) then selects a preferred solution from industry to pursue in more detail. The proposed solutions are called 'systems' in systems engineering.

The preferred solution, and the original requirements, are documented in the form of specifications and usually combined with cost and schedule information to form a legal document known as a contract that allows the process to continue.

3 CHAPTER 3 – PRELIMINARY DESIGN

During preliminary design, the contractor starts to design the system proposed earlier via a process of top-down engineering design. The system is broken down into the proposed set of subsystems and subsystem design occurs. Subsystem design involves the identification of the interfaces between the subsystems and some decisions about how the subsystems should be integrated together. Broader decisions about the use of off-the-shelf technology versus developmental technology are also made during this stage.

4 CHAPTER 4 – DETAILED DESIGN AND DEVELOPMENT

Chapter 4 covers the last stage of design that takes the design to the lowest level required. The lifecycle stage after detailed design is construction and production, so planning for construction is also completed during this stage.

This chapter then discusses the construction and production process highlighting the requirement to design a system that is producible. The chapter also covers the issues associated with the in-service phase of the lifecycle including sustainability issues, reliability and maintainability, and ultimately, the need to dispose of the system

Disposal brings the lifecycle to an end.

5 CHAPTER 5 – SYSTEMS ENGINEERING MANAGEMENT

The previous chapters have investigated the issues associated with systems engineering process at specific points throughout the systems engineering lifecycle. A number of management issues emerge from this investigation. These issues need to be managed consistently throughout the systems engineering lifecycle. Accordingly, the issues are referred to as systems engineering management issues. The systems engineering management issues discussed in this chapter are:

- Systems engineering management planning
- Technical reviews and audits
- Configuration management
- Test and evaluation
- Specifications and standards
- Integration management
- Technical risk management.

Each topic is dealt with separately and its importance and relevance explained.

6 CHAPTER 6 – SYSTEMS ENGINEERING MANAGEMENT TOOLS

There are many tools in existence that support systems engineering management, but the main tools used include systems engineering standards and systems engineering capability maturity models. This chapter selects the main systems engineering standards and maturity models and summarises their contents. The aim of the chapter is not to create expertise in the application of these standards, but to raise awareness of their existence and application. Students are encouraged to source the standards and cover them in more detail as the need arises in their professional lives.

7 CHAPTER 7 – SYSTEMS ENGINEERING PROCESS TOOLS

Chapter 7 investigates some of the broad tools available to engineers and other specialists who are involved in analysis, synthesis and evaluation of problems and their solutions. Some of the more modern computer aided tools are discussed, as are the traditional engineering design tools such as modeling and simulation.

8 CHAPTER 8 – RELATED DISCIPLINES

Systems engineering is a multi-disciplinary effort to solve complex (often) technical problems. Cooperation and communication is required across a broad range of disciplines including technical specialists, project managers, quality assurance, logistics, and legal personnel. This chapter summarises the main focus of some of these disciplines and highlights the role systems engineers play in assisting and informing these 'related' disciplines.

Appendix E

Acronyms

ACME	School of Aerospace, Civil and Mechanical Engineering
ADF	Australian Defence Force
ADFA	Australian Defence Force Academy
AEWC	Airborne Early Warning and Control
AISC	Advanced Integrated Systems Course
CATEI	Course and Teaching Evaluation and Improvement
CO	Commanding Officer
DMO	Defence Materiel Organisation
DSTO	Defence Science and Technology Organisation
EO	Electro-Optic
EW	Electronic Warfare
FST	Fundamentals of Surveillance Technology
GPA	Grade Point Average
GPS	Global Positioning System
INS	Inertial Navigation System
ITEE	School of Information Technology and Electrical Engineering
JSF	Joint Strike Fighter
KSA	Knowledge, Skills, and Attitudes
LEA	Land Engineering Agency
LSI	Learning Style Inventory
MBTI	Myer-Briggs Type Indicator
PWO	Principal Warfare Officer
RAAF	Royal Australian Air Force
RAN	Royal Australian Navy
RAM	Radar Absorbent Material
RNZAF	Royal New Zealand Air Force
S-F	Structure to Fact ratio
SOLO	Structure of the Observed Learning Outcome

SOTL	Scholarship of Teaching and Learning
UAV	Uninhabited Aerial Vehicle
UNSW	University of New South Wales
USQ	University of Southern Queensland

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