USING CONCEPT MAPPING TO SCAFFOLD LEARNING FOR STUDENTS WHO EXPERIENCE LEARNING DIFFICULTIES IN SCIENCE CLASSES

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working memory, scaffolding, concept mapping, dual-coding, knowledge construction, conceptual understanding, learning difficulty, science learning, metacognition
Abstract

In order to develop scientific literacy students need the cognitive tools that enable them to read and evaluate science texts. One cognitive tool that has been widely used in science education to aid the development of conceptual understanding is concept mapping. However, it has been found some students experience difficulty with concept map construction.

This study reports on the development and evaluation of an instructional sequence that was used to scaffold the concept-mapping process when middle school students who were experiencing difficulty with science learning used concept mapping to summarise a chapter of a science text. In this study individual differences in working memory functioning are suggested as one reason that students experience difficulty with concept map construction.

The study was conducted using a design-based research methodology in the school’s learning support centre. The analysis of student work samples collected during the two-year study identified some of the difficulties and benefits associated with the use of scaffolded concept mapping with these students.

The observations made during this study highlight the difficulty that some students experience with the use of concept mapping as a means of developing an understanding of science concepts and the amount of instructional support that is required for such understanding to develop. Specifically, the findings of the study support the use of multi-component, multi-modal instructional techniques to facilitate the development of conceptual understanding with students who experience difficulty with science learning. In addition, the important roles of interactive dialogue and metacognition in the development of conceptual understanding are identified.
Statement of Original Authorship

The work contained in this thesis has not been previously submitted to meet the requirements for an award at this or any other higher education institution. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made.

Signature: ____________________________

Date: ________________________________
Acknowledgements

After many years of working in the fields of science education and later in learning support, when I began this research my broad aim was to investigate why some students experience difficulty with the development of conceptual understanding in science.

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CHAPTER 1

Outlining the Study

1.1 Introduction

This study of scaffolded concept mapping outlines the development, trialling and evaluation of an instructional sequence that was used to enhance the science learning outcomes of a group of at-risk students who were referred to the Learning Support Centre of an independent school in Brisbane, Australia. Science was chosen as the context for this study because of the recognised need in science education to provide all students, including those who experience difficulty with science learning, the opportunity to develop scientific literacy.

The acquisition of scientific literacy has been identified as an essential educational outcome for all students in the 21st century (Hackling, Goodrum, & Rennie, 2001; Millar, 2006; Murcia, 2007; Norris & Phillips, 2003; Powell & Anderson, 2002; Yore & Treagust, 2006). While there is still some discussion about the precise meaning of the term scientific literacy and its implications for the science curriculum (Millar, 2006), two key components have been identified. Firstly, there is a conceptual component that emphasises the need for students to have an understanding of the unifying themes of science and secondly, there is a literacy component that emphasises the need for students to have the cognitive tools and communication abilities to analyse and interpret science texts (Millar, 2006; Yore & Treagust, 2006). It is argued that by developing an understanding of science, students will be better equipped to function in an increasingly more complex scientific and technological...
world (Bereiter, Scardamalia, Cassells, & Hewitt, 1997; Gallagher, 2000; Lederman, 2008; Monero, 1999; Ryder, 2001; Westby & Torres-Velaquez, 2000; Yager, 2000).

After reviewing research that investigated the development of understanding in science, Gallagher (2000) concluded that the process of making connections between elements of new information is not easily attained by many students and that a number of models of teaching and learning have underestimated the amount of support that is needed for this understanding to develop. Gallagher emphasises the importance of the use of learning strategies to support new knowledge construction.

Broadly two perspectives have been used to explain the nature of understanding in science education. The first is conceptual change learning that is related to individual cognitive psychology and views science learning as a process of developing concepts that reflect the reality of the world. The second is a discourse-based perspective that views science as a socially-constructed and contextually-situated activity (Girod & Wong, 2002). Each of these explanations about the nature of knowledge can be placed within an epistemological framework of constructivism. Constructivism is described as an epistemological view of knowledge acquisition that emphasises the process of knowledge construction by describing how students attain, develop and use cognitive processes (Airasian & Walsh, 1997; Applefield, Huber, & Moallem, 2001). The most significant difference between these two perspectives is the role given to language in the development of scientific understanding. Conceptual change learning has been related to a first-generation interpretation of cognitive science that views language as a by-product of thought, while a discourse-based perspective has been related to a second-generation interpretation of cognitive science that views language as means of
both constructing and representing understanding (Hand & Prain, 2006; Klein, 2006; Yore & Treagust, 2006).

One constructivist learning strategy that has been widely used in science education as a tool in fostering the development of a more integrated understanding of knowledge domains is concept mapping (Fensham, Garrard, & West, 1981; Klein, 2006; Mintzes, Wandersee, & Novak, 2001; Novak, 2005; Novak, Gowin, & Johansen, 1983; White & Gunstone, 1992). Novak and Canas (2006) suggest that one of the reasons that concept mapping has been so useful in facilitating the development of conceptual understanding is that it provides a scaffold for the organisation and structuring of knowledge.

Concept maps have been described as information structures that show the core elements of conceptual relationships in a hierarchical graphic network of nodes and links using two-dimensional space. Nodes are labelled boxes that are used to represent concepts. In order to represent the relationships between concepts, nodes are connected by links which are verbs or short phrases written on the lines connecting the nodes (Mintzes & Wandersee, 1998; Novak & Canas, 2006; Romance & Vitale, 1999). However in this study, in addition to the hierarchical conception of concept maps, the term has been used to include spoke, chain and network structures (Chang, 2007; Kinchen, Hay & Adams, 2000; Williams 1998).

Because of the difficulties that some students experience with the process of concept map construction (Novak & Canas, 2006) researchers have begun to investigate additional levels of scaffolding that might be required to improve learning outcomes.
Scaffolding is a process that enables a learner to achieve a learning outcome with assistance. A scaffold can be described as the temporary and flexible support that is required for learning to occur. A key feature of scaffolded instruction is the ongoing interaction between the teacher and the learner during the completion of a task (Palincsar, 1986). Central to the idea of scaffolded instruction is Vygotsky’s notion of the student’s zone of proximal development (Jaramillo, 1996). Vygotsky believed that in order for students to learn concepts they need to be actively involved in learning activities that are just above their current level of knowledge and skill. Within this approach the role of the teacher is that of a facilitator who guides the students’ interaction with the learning experiences, from one level of performance to another, in keeping with their zone of proximal development, by using modelling and scaffolding techniques until finally there is independent performance of the task. While working on the task the learner’s performance is continually monitored so that the level of difficulty and amount of instructional support can be adjusted (Jaramillo, 1996; Palincsar, 1986; Palincsar & Brown, 1988).

Studies conducted by Chang et al. (2002) and Katayama and Robinson (2000) suggest cognitive overload as a reason for the difficulties that some students experience with concept map construction. Cognitive load relates to the degree to which the learner’s limited working memory capacity can cope with the processing demands of a learning task. If the task has a high degree of complexity, processing demands may exceed the learner’s limited working memory capacity and impose a high cognitive load (Kalyuga, Chandler, & Sweller, 1998; Yeung, 1999). Working memory is a term used to describe the mental workspace where information can be stored and processed.
during the performance of cognitive tasks (Gathercole & Pickering, 2000). Individual differences in the functioning of working memory have been linked to performance in the areas of reading (Baddeley, 1984; Swanson, Cochran, & Ewers, 1989), reading comprehension (Baddeley, Logie, Nimmo-Smith, & Brereton, 1985), mathematics (Swanson & Sachse-Lee, 2001b; Wilson & Swanson, 2001), writing (Hooper, Swartz, Wakely, de Kruijff, & Montgomery, 2002), language development (Shankweiler & Crain, 1986), reasoning (Gilhooly, 1998; Phillips & Forshaw, 1998; Rabinowitz, Howe, & Saunders, 2002) strategy utilisation (Blote, Resing, Mazer, & Van Noort, 1999; Woody-Dorning & Miller, 2001) and the development of conceptual knowledge in science (Novak & Canas, 2006; Yore & Treagust, 2006).

It has been suggested that one means of increasing effective working memory capacity is by the dual processing of information through both the verbal and visual modes of the working memory system (Gerlic & Jausovec, 1999; Sweller, Van Merrienboer, & Pass, 1998). Studies conducted by Chang et al. (2001, 2002) have investigated the use of a number of verbal and visual scaffolding techniques to reduce the cognitive load associated with the concept-mapping process. In addition to research that has used verbal and visual scaffolding to reduce the high cognitive load associated with concept map construction, a number of studies have investigated the benefits of the use of collaborative dialogue in the learning of science concepts during the concept-mapping process (Daley, Shaw, Balistrieri, Glasenapp, & Piacentini, 1999; Stoyanova & Kommers, 2002; Van Boxtel, Van der Linden, Roelofs, & Erkens, 2002). The results of these studies support the view that the explicit discussion of the relationships between science concepts benefits the development of conceptual knowledge (Klein, 2006).
1.2 Aims of the Study

One group of students who experience particular difficulty with the development of understanding in science are those with learning difficulties (Dole, 2000). These difficulties have been related to the complexity of science content (Baker, Gersten, & Scanlon, 2002; Gajria, Jitendra, Sood, & Sacks, 2007), the complex nature of science texts (Dole, 2000; Fang, 2006) and the complexities associated with science teaching (Palincsar, Anderson, & David, 1993). Because of the difficulties that some students experience with the development of understanding in science, it has been suggested that there is a need to investigate the impact of multi-component strategy interventions on science learning outcomes (Hand & Prain, 2006; Lenz, Adams, Bulgren, Pouliot, & Laraux, 2007).

The current study reports on the development, trialling and evaluation of a multi-component instructional sequence that used a combination of verbal and visual scaffolding activities to facilitate the process of concept map construction when students who were experiencing difficulty with science learning used concept mapping to summarise a chapter of a science text. The study also sought to establish whether some of the students who were experiencing difficulty with science learning had individual differences in their working memory functioning and to investigate how such individual differences might influence the type of scaffolding that was required.

Within the Learning Support Department, in my School, it is important that any instructional approach that is to be implemented in the student’s learning support sessions can be implemented by all learning support staff, both teachers and teacher
aides at a level that ensures consistent service delivery. In order to identify how the instructional approach could be implemented within the Learning Support Department, the study also included an evaluation of the implementation of scaffolded concept mapping using teacher aide assistance.

The investigation was guided by the following research questions.

1. To what extent do students who experience difficulty with science learning have working memory profiles that identify individual differences in working memory functioning?

2. How can the scaffolding of the concept-mapping process be used to aid the development and representation of conceptual knowledge in students who experience difficulty with science learning?

3. How can teacher aides be used to implement scaffolded concept mapping in students’ learning support sessions?

4. Can individual differences in students’ working memory functioning be used to explain the observed changes in the development of conceptual knowledge that occurred when students who were experiencing difficulty with science learning used a scaffolded concept mapping strategy?

These questions were derived from the review of the literature relating to working memory and concept mapping conducted in Chapter 2.
1.3 Context of the Study

The study was conducted in an independent, co-educational school situated in Brisbane, Australia. The School is divided into three sub-schools. Students attend the Junior School from Preparatory Year to Year 6 (5 years to 11 years), the Middle School from Years 7 to 9 (12 years to 14 years) and the Senior School from Years 10 to 12 (15 years to 17 years). Instruction is given in mixed-ability classes over a wide range of subject areas. Within the School all students are required to study Science as a core subject to Year 10. The development of scientific literacy is a key component of the science curriculum.

If students are found to be experiencing difficulty with their coursework in the key subject areas, they are given the opportunity of reducing their subject load and attend Learning Support in order to gain additional assistance in core subject areas one of which is Science. In the Learning Support Centre, learning support teachers and teacher aides work with students either individually or in small groups to assist students in developing their literacy skills.

In recent years the School conducted a review of its curriculum from Preparatory Year to Year 9. This curriculum review was conducted using a constructivist theoretical framework. One of the outcomes of the review was the identification of a number of key learning strategies that could be used by teachers and students to facilitate the construction and representation of knowledge. One of these strategies was concept mapping. Currently, within the School there has been no formal evaluation of the way in which these learning strategies should be utilised with students who are experiencing difficulty with learning in particular knowledge
domains. However, it has been found that when these students have attempted to use a concept mapping strategy to represent information contained in their science textbook, they experience considerable difficulty with map construction and are very reluctant to use the strategy independently.

In keeping with the goal of the development of scientific literacy for all students (Millar, 2006; Yore & Treagust, 2006) there is a need within the School to investigate how learning strategies such as concept mapping can be used as cognitive tools to improve the development and representation of conceptual knowledge with students who are experiencing difficulty with science learning. One methodology that has been used to develop evidence-based claims about learning through the investigation of cognition in context is design-based research (Barab & Squire, 2004).

1.4 Study Methodology

Design-based research has been described as an emerging research paradigm of experimental research for the study of the issues of learning that bridges theoretical research and educational practice. It uses the principles of science research to investigate and understand teaching and learning processes where the researcher is actively involved as an educator within the classroom. This research takes place through the ongoing processes of design, implementation, evaluation and redesign. Design-based research educational interventions are viewed holistically through the study of the interactions between instructional materials, teachers and learners and are often conducted within a single setting over a long period of time. This type of research is often distinguished by a detailed description of the evolving design process. These narrative accounts can be used as data for the development of theory
and to redesign instructional activities over time (Design-Based Research Collective, 2003; Kelly, 2003; Shavelson, Phillips, Towne, & Feuer, 2003).

1.5 The Researcher

The development of conceptual understanding has long been a goal of science education. My own involvement in science education began in the early 1970s when I completed a degree in Science, majoring in Biochemistry. At that time there was a move away from teaching science as a body of knowledge to an approach that emphasised science processes (Hodson, 1985). The essential characteristic of this approach was that it emphasised the skills of science by using investigation and problem solving as the basis of the teaching method. That is, it hoped to enhance the development of understanding by focusing on the way scientists work rather than on a defined body of content (Millar & Driver, 1987). By the 1980s the effectiveness of process approaches had begun to be questioned and approaches to science teaching that attempted to take into consideration both the learner’s background knowledge and current theoretical developments in cognition had begun to emerge (Driver & Oldham, 1986; Finley, 1983).

As a result of working as a science teacher for a number of years in mixed-ability classrooms I had gained a deep awareness of the difficulties experienced by some students in developing and representing their knowledge of science concepts. In the early 1990s I completed my Masters in Special Education. This study allowed me to develop further my understanding of the ways in which individual differences in cognitive functioning influence student learning. Since that time my teaching practice has been involved in the area of Learning Support. The current research study has
particular significance for my own teaching practice, as part of my role as Head of Learning Support involves the evaluation of the effectiveness of learning strategies that are currently being used within the School to improve students’ learning outcomes in specific knowledge domains.

1.6 Overview of Thesis

In order to ensure that all students are provided with the opportunity to develop scientific literacy it is necessary to develop models of teaching and learning that take into consideration the individual differences that students bring to the instructional context (Airasian & Walsh, 1997; Bischoff & Anderson, 1998; Hand & Prain, 2006; Taber, 2000). One group of students who have been found to have difficulty in accessing the general education curriculum (Baker et al., 2002) and in developing an understanding of challenging content areas (DeCecco & Gleason, 2002; Lenz et al., 2007) are those students who experience difficulty with reading comprehension. This is particularly true when the students are required to engage in the reading of informational texts to develop understanding in science (Gajria et al., 2007; Hand & Prain, 2006; Palincsar et al., 1993). In a review of the learning outcomes that resulted from the use of concept mapping, Nesbit and Adesope (2006) concluded that there was a particular need for research on the use of concept maps with students in the secondary school who have been identified with reading difficulties when concept mapping was used as a note-taking activity to develop reading skills.

The current study investigated the development and evaluation of a multi-component instructional sequence that used a combination of verbal and visual scaffolding techniques to facilitate the process of concept map construction with a group of Year
8 and Year 9 students who were experiencing difficulty with science learning. The study also investigated the individual differences in working functioning of students who were experiencing difficulty with science learning and whether these differences influenced the type of scaffolding that was required. In keeping with the view that there is a need in science education to investigate students’ understanding of science concepts using real curriculum materials (Gajria et al., 2007) in real learning contexts (Nesbit & Adescope, 2006; Palincsar et al., 1993), the study was conducted using a design-based research methodology in the School’s Learning Support Centre.

The study was conducted in three stages. In the first part of Stage 1 of the study, a student, identified as James, who was experiencing difficulty with science learning was assessed using a Working Memory Assessment Battery that was compiled using subtests from the Test of Memory and Learning (Reynolds & Bigler, 1994), the Test of Auditory-Perceptual Skills: Upper Level (Gardner, 1994) and the Swanson Cognitive Processing Test (Swanson, 1996). In the second part of Stage 1 of the study the researcher worked with James to develop and implement the scaffolded concept mapping process. A design-based research methodology was used to design, implement, evaluate and redesign the first four trials of the scaffolded concept-mapping process.

In Stage 2 of the study, the researcher re-evaluated the scaffolded concept-mapping process used in Trial 4 of Stage 1 of the study with a second student, identified as Sam, who was also experiencing difficulty with science learning. This student was assessed using the Working Memory Assessment Battery. In Stage 3 of the study, the scaffolded concept-mapping process, developed in Trial 4 of Stage 1, was
implemented by a learning support teacher aide working under the supervision of the researcher with a third student, identified as Tim. This student was assessed with the *Working Memory Assessment Battery*. The scaffolded concept-mapping process was then implemented with an additional group of learning-support teacher aides who worked under the supervision of the researcher.

The theoretical framework that was used to guide the development of the *Working Memory Assessment Battery* and the development and evaluation of the scaffolded concept-mapping process is discussed in Chapter 2.

The methodology and methods that were used to guide the construction of the *Working Memory Assessment Battery* and the development and evaluation of the scaffolded concept-mapping process are outlined in Chapter 3.

A description of the design, implementation, evaluation and redesign of the scaffolded concept-mapping process used with James and Sam during Stages 1 and 2 of the study is given in Chapters 4 and 5.

An evaluation of the scaffolded concept-mapping process developed in Stages 1 and 2 of the study is provided in Chapter 6.

Chapter 7 provides an evaluation of Tim’s working memory profile and details of the implementation of the scaffolded concept-mapping process using teacher aide assistance.
Chapter 8 provides a discussion of the findings of the study.

Chapter 9 outlines the conclusions and possible directions for further study.
CHAPTER 2

The Development of a Theoretical Framework

In Chapter 1, cognitive load and associated limitations in working memory capacity were identified as possible factors that can impact on the development of conceptual knowledge during the performance of a concept-mapping task (Chang et al., 2002). The current chapter outlines the development of the theoretical framework that was used to investigate whether the scaffolding of the concept-mapping process can be used to facilitate the development of conceptual knowledge with students who are experiencing difficulty with science learning. The chapter begins with the identification of the main theoretical influences that have impacted on our understanding of the concept-mapping process and with an overview of information processing theory. It continues with an elaboration of the human memory system and with a discussion of the interaction between the memory, knowledge and strategy components of the information processing system. It then outlines research that has investigated concept mapping and concludes with a discussion of some instructional techniques that can be used to scaffold the concept-mapping process.

2.1 Theoretical Influences on the Development and Use of Concept Maps

Concept maps were developed in response to the need to find a tool that could be used to track children’s conceptual development in science. Since that time they have become widely used as an instructional technique to facilitate meaningful learning (Novak et al., 1983; Novak, 2005; Novak & Canas, 2006).
One cognitive view of learning that had a marked impact on the development and use of concept maps was the *assimilation theory of learning* outlined by Ausubel (1968). In this theory Ausubel recognised the active role of the learner in the knowledge construction process. Novak (2005) identifies three aspects of the work of Ausubel that impacted on the development of concept maps. The first is the influence of the student’s prior knowledge on the development of new meaning. The second is that the content of a particular subject-matter discipline is stored in a hierarchical structure in memory, and the third is that when meaningful learning occurs, the relationships between concepts become more explicit and more highly integrated with other concepts (Novak, 2005; Novak et al., 1983).

Additional Ausubelian concepts that are related to meaningful learning and that influenced the development of concept maps include: *subsumption*, which refers to the process by which new knowledge is linked to more general concepts that already are part of the learner’s cognitive structure and *superordinate learning* which refers to the process by which new, more general concepts are acquired through the reorganisation of the learner’s cognitive structure. Subsumption and superordinate learning are said to occur through a process of *progressive differentiation* which refers to the gradual elaboration and clarification of concept meanings (Ausubel, 1968; Mintez & Wandersee, 1998; Novak, 2005). In addition to the role of prior knowledge, Ausubel (1968) recognised the role of language in concept formation in two ways. Firstly, because the representational properties of words facilitate the combinational and transformational processes of thought and secondly through verbalisation in
propositional form, ideas can become more refined and as a result become more precise and explicit.

While the work of Ausubel (1968) had a marked impact on the initial development of the concept-mapping process, more recently a number of additional theoretical perspectives have contributed to advancing our understanding of the development of conceptual knowledge during the process of concept map construction. These include the influence of constructivist views of learning that also emphasise the role of prior knowledge and language in the process of knowledge construction (Airasian & Walsh, 1997; Hand and Prain, 2006; Klein, 2006; Yore & Treagust, 2006) and current views of cognitive psychology that can be used to identify the underlying cognitive mechanisms that operate within the human memory system during the knowledge construction process (Airasian & Walsh, 1997; Gordon & Olson, 1998; Novak & Canas, 2006; Yore & Treagust, 2006).

In order to develop a theoretical framework that can be used to examine how individual differences in working memory functioning can influence the development of conceptual knowledge during the process of concept map construction, this discussion continues by identifying the nature of the cognitive mechanisms that mediate knowledge construction. One approach that has been widely used to investigate and describe the cognitive basis of individual differences during task performance is *information processing theory* (Kolligian & Sternberg, 1987; Swanson, 1988).
Broadly, two different metaphors have been used to describe the human information processing system. These are the mind as a computer and the mind as a brain. The basic assumption that underpins information processing in computers is that for processing to occur, there is some kind of physical symbol that undergoes manipulation. Thus, the computer becomes a general machine that operates on symbols that do not require any form of internal organisation to give them meaning. Meaning is derived from the rules that manipulate them. Within the symbol-manipulation conceptualisation of information processing, knowledge networks are envisaged as static permanent structures that are operated on by active strategic processes that are dynamic and transformational. In contrast, the mind as a brain description suggests that knowledge can be activated and accessed independently of a rule-based system (Anderson, 1982; Rabinowitz & McAuley, 1990). Most of the research that has investigated the knowledge/strategy interaction has been oriented toward the mind as a computer metaphor. However, neither of these information processing models alone seems to be able to explain adequately both the active nature of conceptual knowledge and the control of processing that is provided by strategy use.

In order to explain how strategic and conceptual processing might interact, a hybrid model that describes a symbiotic relationship between strategies and the development of knowledge has been suggested (Rabinowitz & McAuley, 1990). Within this model it is proposed that skills develop initially from needing to be strategically driven, to a situation where information is derived from the knowledge base itself. It is within this hybrid conceptualisation of the knowledge/strategy interaction that the theoretical
framework used in the current study to explain the operation of the components of the information processing system during the performance of a concept-mapping task, is developed.

Models of information processing encompass three basic constructs (Montgomery, 2002). These are a representation component, which describes where information will be encoded and stored, a process component that manipulates and transforms information, and an attention or executive component that maintains information in an active state and monitors the learner’s activities.

One information processing approach that uses these three basic constructs to explain how individual differences in the components of the information processing system can influence task performance is the componential-deficit theory of learning disability described by Kolligian and Sternberg (1987). These components include firstly the meta-components, the higher order executive components that are used to plan, monitor and evaluate progress. Secondly, the performance components, the lower order processes that carry out the plans developed by the meta-components, and finally there are the knowledge-acquisition components, which are the lower order components that are used to learn new information. Similarly, Swanson (1988) identifies the complex nature of learning disabilities by using a multi-directional model to describe the interaction between the components of the information processing system during task performance. The components in this model are the knowledge base, which includes language competence, working memory, understanding ability and semantic memory, an executive function which includes direction and organisation, a strategy component which includes prediction,
summarization and strategy transformation, and a metacognitive component which includes perception and awareness. Swanson describes the goal of education as the smooth coordination of the mental components of the information processing system during the performance of a learning task.

While each of these information processing models of learning disability differ in the ways in which the individual components are identified, within a general conception of the human information processing system there are two areas where individual differences can be investigated. Firstly, there are the quantitative differences in the parameters describing the basic hardware of the system such as working memory capacity, and secondly, there are the quantitative and qualitative differences in the way in which the individual’s knowledge base is represented in memory (Campione & Brown, 1978; Chi & Gallagher, 1982).

In order to understand the nature of the interaction between working memory capacity and the development of conceptual knowledge during the process of concept map construction, the functioning of the memory component of the human information processing system is now discussed. This is followed by a consideration of the relationship between working memory and the development of conceptual knowledge.

2.3 The Human Memory System

In general, descriptions of the human memory system include three memory stores: the sensory memory, the short-term/working memory and the long-term memory. Information enters the system through our sense organs and is then received by our sensory memory. The sensory register holds information for approximately one to
four seconds. If information is required for longer periods of time it is transferred into the short-term/working memory system where all new information is processed and conscious mental processes are performed. This is described as a limited capacity system that can only hold information for approximately ten to twenty seconds. To keep information activated in working memory for longer periods of time the process of rehearsal can be used. The limitations imposed by working memory capacity can be overcome in a number of ways. These include the chunking of information, the development of automatic processing by the enhancement of background knowledge and through the use of learning strategies that enable the reorganisation of new information. The third component of the human memory system is long-term memory. This is where all of the information that we have learned is stored (Banikowski & Mehring, 1999; Bourne, Dominowski, & Loftus, 1979).

In recent years the exact nature of the components and processes that makes up the human memory system has been the subject of significant debate (Baddeley, 1992; Parkin & Hunkin, 2001). There are currently a number of models of memory that attempt to clarify the operational relationship that exists between short-term memory, working memory and long-term memory. In order to understand the complex operational relationship that exists between short-term memory, working memory and long-term memory during the performance of a concept-mapping task some of the current models of working memory that incorporate these three components are now discussed. In the current study short-term memory, working memory and long-term memory are considered to be interrelated aspects of the one memory system (Baddeley, Papagno, & Vallar, 1988; Swanson, 1986; Swanson, 1994).
2.3.1 Current Models of Working Memory

One model of working memory that draws heavily on the dynamic nature of long-term memory is the long-term working memory model proposed by Ericksson and Kintsch (Kaakinen, Hyona, & Keenan, 2003). It is suggested that when concepts are encoded into short-term memory, this activates the retrieval of whole subsets of information from the long-term memory store. This activated information is long-term working memory. If the learner has high prior knowledge there is quick access to the learner’s knowledge base through long-term working memory and this facilitates the encoding of new information. If the reader does not have high prior knowledge, the understanding of new information has to rely on the use of short-term working memory. Within this model, short-term working memory is thought to be a limited-capacity resource, whereas long-term working memory capacity is not fixed but varies with the learner’s expertise in a particular knowledge domain (Gobet, 2000).

A second conceptualisation of working memory that has been used extensively to guide research that has investigated the relationship between working memory and task performance was proposed by Daneman and Carpenter (1980). Within this model, working memory is described as a limited-capacity system that has both processing and storage functions. During the performance of a complex task, information can become part of working memory through perceptual encoding, through retrieval from long-term memory or as the product of processing itself. It is suggested that differences in working memory capacity may lead to tradeoffs between processing and storage functions and that a larger processing capacity may provide greater opportunity for a particular piece of information to be integrated into the individual’s knowledge structures.
A third model of working memory that has been used in the investigation of individual differences in task performance is the three-component model proposed by Baddeley (1981). The main components of this model are two domain-specific storage structures, the phonological loop, that is responsible for the maintenance of verbal-linguistic information and the visuo-spatial sketchpad that maintains visual and spatial information and a third component, the central executive that has domain-general processing functions (Baddeley, 1992; Gathercole & Pickering, 2000; Swanson & Siegel, 2001).

The first of the domain-specific storage structures, the phonological loop is thought to consist of two subcomponents. These are a short-term phonological store and an articulatory rehearsal process. Memory traces within the phonological store are thought to decay after approximately two seconds unless maintained by a sub-vocalisation rehearsal process that allows for the maintenance of verbal information in the articulatory system. The process of sub-vocal articulation also seems to be involved in the recoding of visually represented information within the phonological loop (Baddeley, 2002). Recent research conducted by Baddeley, Chincotta, and Adlam (2001) suggests a more active and executive role for the phonological loop that relates to the verbal control of action. It is suggested that this proposed function of the phonological loop may be similar to the concept of inner speech that is a significant feature of the work of Vygotsky. The second domain-specific storage structure, the visuo-spatial sketchpad, is said to be responsible for the processing and storage of visual or spatial information and for linguistic information that can be recoded into an imaginal form (Baddeley, 2002; Swanson & Siegel, 2001).
The central executive has been broadly described as a limited-capacity pool of general processing resources. Over time the central executive has been given a variety of roles. Initially the central executive was thought to be responsible for the retrieval of information from long-term memory, the co-ordination of information from the phonological loop and the visuo-spatial sketchpad, and the regulation of the flow of information through working memory during task performance. However, more recently the central executive is now seen as a purely attentional control system, with the retrieval of information from long-term memory no longer considered as one of its roles (Baddeley, 2002). The functional emphases of the central executive include its ability to focus, divide and switch available attention (Baddeley et al., 2001; Gathercole & Pickering, 2000), and its ability to maintain information in the service of ongoing cognitive activities such as language comprehension and reasoning (Kane, Tuholski, Hambrick, Wilhelm, Payne, & Engle, 2004).

One of the problems associated with the tripartite model of working memory originates from the need to integrate information from long-term memory with information from the subsidiary systems in a way that permits the active maintenance and manipulation of information. This role has now been given to a new fourth component of the system, an episodic buffer, which is assumed to represent a storage system that uses a multi-modal code. It is considered to be a limited capacity system that forms an interface between the two sub-systems and long-term memory (Baddeley, 2002).
The integrated functioning of the working memory system within the current four-component model is described by Baddeley (2002). It is proposed that in order to comprehend a complex message, current representations relating to the topic that are held in long-term memory are activated. These representations are then placed into the episodic buffer and are maintained within the buffer using the limited resources of the central executive. Information that has been encoded through one of the two subsystems comes into contact with this information in the episodic buffer and a new knowledge structure is formed. This newly formed representation is then consolidated in long-term memory. Thus, the capacity to maintain information in the episodic buffer would depend on not only the capacity of the buffer itself but also on the capacities of the two domain-specific storage systems and the central executive. The four-component model now identifies specific links between the two domain-specific storage systems and verbal and visuo-spatial long-term memory with the flow of information being bi-directional.

Finally, a fourth model of working memory has been proposed by Hambrick, Wilhelm, and Engle (2001). It has two major components. The first component of this system is the short-term memory, which refers to those representations from the long-term memory that are currently activated above the activation threshold. In keeping with a connectivist framework, this information from long-term memory has become activated by some external stimulus or as a result of a spreading activation through the long-term memory network. It is proposed that the phonological and visuo-spatial storage systems identified by Baddeley (1992) are not structurally distinct storage components but are simply different representational formats or methods of rehearsal. The second component of the system is said to be a domain-free executive function
referred to as working memory capacity. This is analogous to the central executive proposed by Baddeley. It is a domain-general limited capacity resource that is responsible for the maintenance of task-relevant information during the performance of a complex task.

Each of the models of working memory that have been described presents a different interpretation of the operational relationship that exists between the long-term, short-term and executive components of the complex working memory system. Broadly, three main areas of difference emerge. The first is whether or not the working memory system should be described as a single or distributed workspace with domain-specific and domain-general functions that operate in separate locations within the brain. The second is whether or not working memory should be regarded as a single-capacity system with its total capacity shared across each of its components or as a multi-component system each with an individual memory capacity. The third is how the interaction between working memory and the information contained in long-term memory is thought to occur. These comparisons of the working memory models are outlined below.

Hambrick et al., (2001) suggest that the phonological and visuo-spatial components of working memory are not structurally distinct storage components while Baddeley (2002) identifies separate components where domain-specific and domain-general processing are said to occur. Baddeley’s distributed-workspace model is supported by evidence from the area of neuropsychology. Studies reported by Swanson and Siegel (2001) and Pickering (2006) using functional magnetic-resonance imaging and positron emission tomography, support the view of separate neural locations for the
storage and rehearsal components of the phonological and visuo-spatial subsystems. Phonological activity has been found to be located mainly in the left hemisphere of the brain while visuo-spatial activity is located in the right hemisphere. Executive functioning has been found to be located in the frontal lobe. Students who experience difficulty with learning have been found to have processing difficulties relating to parts of the frontal lobe, the parietal lobe and interhemispheric transfer across the corpus callosum (Swanson & Siegel, 2001). A study reported by Baddeley (2002) used functional magnetic-resonance imaging to support the existence of the additional episodic buffer that allows for the temporary storage and integration of information.

The second significant difference between each of the models is the way in which memory capacity is defined. The model proposed by Baddeley (2002) endows each of the subcomponents of working memory with an individual capacity, while the model proposed by Daneman and Carpenter (1980) suggests a shared-capacity system. A study by Bayliss, Jarrold, Gunn, and Baddeley (2003) confirmed that the processing efficiency and storage capacity of each component of the working memory system accounts for unique variance in complex task performance. That is, domain-general storage is separate from domain-specific storage. This separation of the functioning of the domain-specific and domain-general subcomponents of working memory is also supported in studies by Brainerd and Kingma (1985) and by Swanson (1994) who concluded that the short-term memory and working memory performance of learning disabled and normally achieving children and adults, accounted for separate variance in reading comprehension and mathematics tasks.
Lastly, the activation of information from long-term memory is a significant feature of both the long-term working memory model (Kaakin et al., 2003) and the two-component model (Hambrick et al., 2001). Baddeley (2002) now gives greater consideration to the importance of the activation of knowledge from the long-term memory store. By including the episodic buffer in his current working memory model, he has acknowledged the need for a location where the information that has been encoded through the verbal and visuo-spatial components of the working memory system can be maintained and integrated with the information from long-term memory. This recognition of the importance of the integration of knowledge during interactive working memory processing is also a significant feature of the work of Daneman and Carpenter (1980).

The current study was guided by the following assumptions relating to the functioning of the working memory system.

1. That the site of information exchange during complex task performance is working memory (Baddeley, 2002; Novak & Canas, 2006; Sweller et al., 1998).

2. That working memory consists of domain-specific and domain-general storage and processing components, each of which has an individual functioning capacity (Baddeley, 2002; Bayliss et al., 2003; Pickering, 2006; Swanson, 1994; Swanson & Sachse-Lee, 2001a).

3. That the accessibility of information from long-term memory has a significant impact on the functioning of the complex working memory system (Baddeley, 2002; Kaakin et al., 2003; Hambrick et al., 2001).
4. That when new knowledge structures are being constructed within the working memory system during complex task performance, the process of knowledge construction needs to be strategically driven (Rabinowitz & Macaulay, 1990).

A conceptualisation of the model of the working memory system used in the current study is represented in Figure 2.1.
The information processing subcomponents that represent the locations where the storage and processing of verbal and visuo-spatial information occur are identified at the centre of the model. During the performance of a processing task, incoming verbal information is initially stored in the phonological store and if required, rehearsed in the articulatory system before entering the episodic buffer where it will interact with information that has been activated from long-term memory. Similarly, visuo-spatial
information enters the system through the visuo-spatial sketchpad where it is initially stored and then transferred to the episodic buffer for interactive processing (Baddeley, 2002).

The functioning of the central executive is represented by the outer circle in the model. The central executive is considered to be a limited-capacity attentional-control system that has the ability to switch available attention to maintain information in the support of ongoing cognitive activity. Executive processes are called into play when the multiple components of the cognitive architecture need to be co-ordinated. At this time the executive processes are used to maintain associations in high demand processing situations (Baddeley, 2002; Kane et al., 2004).

The two most significant sources of individual difference in this model of working memory that have the potential to restrict the interaction of concepts and propositional frameworks in working memory system during the performance of a concept-mapping task are, the individual capacities of each of the subcomponents of working memory (Baddeley, 2002; Bayliss et al., 2003; Swanson, 1994; Swanson & Sachse-Lee, 2001), and the availability of knowledge from long-term memory (Baddeley, 2002; Kaakinen et al., 2003; Hambrick et al., 2002).

Previous research has found that students with learning difficulties have individual differences in the functioning of each of the subcomponents of working memory (Cornoldi, Carretti, & De Beni, 2001; Gathercole & Baddeley, 1989; Gathercole & Pickering, 2000; Pickering & Gathercole, 2004; Swanson & Sachse-Lee, 2001b; Wilson & Swanson, 2001) with knowledge availability (Baker et al., 2002; Bos &
Anders, 1990) and with strategy utilisation (Borkowski, Carr, & Pressley, 1987; Torgensen, 1982).

This chapter continues with a discussion of the way in which individual differences in working memory functioning and knowledge availability can impact on conceptual development during the concept-mapping process. The discussion begins with a consideration of how individual differences in working memory can impact on the development of conceptual knowledge.

2.4 Individual Differences in Working Memory Functioning and the Development of Conceptual Knowledge

A number of studies that have investigated the operation of working memory have linked individual differences in working memory functioning to the development and utilisation of the linguistic knowledge base. These include vocabulary development (Baddeley et al., 1988; Gathercole, 1990), sentence memory (Mann, Lieberman, & Shankweiler, 1980), writing (McCutchen, 2000) and language comprehension (Just & Carpenter, 1992; Lieberman & Shankweiler, 1985; Mann, Shankweiler, & Smith, 1984). Given the renewed interest in the role of language in the development of science understanding (Hand & Prain, 2006; Klein, 2006; Prain & Waldrip, 2009; Yore & Treagust, 2006) a consideration of the link between individual differences in working memory functioning and language development may have particular significance for our understanding of science learning.
2.4.1 Working Memory Functioning and Vocabulary Development

Baddeley et al. (1988) conducted research with a patient, identified as PV, who was a woman who had suffered a left-hemisphere stroke. The authors showed that memory performance could be explained using the working memory framework if it was assumed that PV had an impairment of the phonological store but was otherwise intellectually unaffected. Results showed that PV had an unimpaired capacity to learn associated meaningful words. However, when memory span for non-words was assessed it was found that she performed perfectly only when required to repeat single disyllabic items. She never achieved success in repeating back non-words that consisted of four or five syllables. It was assumed that PV’s impaired capacity to repeat back polysyllabic non-words reflected a deficiency in the operation of her phonological store. The authors suggested that the process of long-term learning may require the maintenance of incoming phonological material in the phonological store and that an important function of the short-term phonological store is its involvement in the learning of new words.

A second study that has investigated the link between phonological memory and vocabulary development was conducted by Gathercole (1990). A group of children who exhibited generalised deficits in the areas of vocabulary, reading and comprehension but whose verbal intelligence was in the normal range for their age were selected for the study. Phonological memory was measured using a non-word recognition task that required the children to repeat single non-words that varied in length and phonological complexity. The results showed that the low phonological memory group took longer to learn nonsense names than did the high memory group. It was proposed that stable phonological representations of familiar words were
constructed from the temporary representations set up in the articulatory loop and that the construction of sound sequences in long-term memory may depend on the quality of the temporary phonological representations. This in turn may influence the speed with which children learn new words.

Further evidence that suggests a link between phonological deficits and vocabulary knowledge has come from research using an object-naming task (Katz, 1986). Children from third grade classes who differed in reading ability were asked to name line drawings of objects as quickly as possible. In order to obtain evidence that the failure to name objects resulted from a phonological deficit, responses were analysed in a number of ways. These included the degree of phonetic relationship between the correct response and the correct object name, the children’s awareness of the length of the names of the objects that were named incorrectly and the effect of word length and word frequency on the number of errors made.

Results showed that poor readers named significantly fewer objects than either average or good readers. The difference was found to persist when naming scores were adjusted to eliminate unfamiliar objects. The difficulty in naming objects was particularly obvious for objects with low frequency names or polysyllabic names. Katz proposed that because uncommon names were heard less frequently, poor readers who have a phonological deficit require more experience both in establishing a usable phonological representation and also in processing these representations for output. With reference to the difficulty associated with the naming of long words, the author proposed that words with longer names cause a problem because more phonological information is required to be represented and processed.
Lastly, a study by Cain, Oakhill, and Lemmon (2004) examined the ability of children aged 9-10 with good and poor reading comprehension skills to infer the meaning of new vocabulary items from context. Results of the study indicated that children with poor reading comprehension skills were less able than good readers to infer the meaning of new vocabulary from context. The poor readers experienced greatest difficulty in providing an appropriate meaning for a new word when it was separated from useful context by filler text. Children who had poor comprehension and poor vocabulary skills were found to have difficulty learning new vocabulary items by both inferring and through direct instruction. These difficulties were related to the high processing demands that were placed on working memory capacity. If readers are required to integrate several ideas that are spaced throughout the text in order to develop the meaning of a new word, the high processing demands of the task will have an adverse effect on those learners who have a limited working memory capacity.

Thus, research studies have shown that limitations in working memory functioning can be linked to students’ learning and understanding of new vocabulary from text. A second aspect of language processing that has been linked to limitations in working memory functioning is sentence memory.

2.4.2 Working Memory Functioning and Sentence Memory

A study that supports the link between working memory capacity and the recall of the content and order of verbal material was conducted by Mann et al., (1980). The ability
of 30 good and poor second-grade readers to remember sentences and word strings was assessed. Children were asked to listen to material and then repeat it. Results indicated good readers were better than poor readers when required to recall spoken words, even when those words were included in meaningful sentences. It was suggested that this difficulty with the recall of words and sentences was related to a failure to make full use of phonetic coding in working memory. A third aspect of language processing that has been linked to limitations in working memory functioning is writing.

2.4.3 Working Memory Functioning and Writing

A model of writing that links limitations in working memory functioning to the interaction that occurs between language encoding processes and the information contained in long-term memory during the writing process, has been described by McCutchen (2000). Encoding processes are divided into transcription processes, that include spelling, and handwriting and text generation processes that include content selection and syntax. The information that is stored in long-term memory is associated with genre and topic knowledge. If transcription and text generation processes do not develop sufficient fluency, the constraints imposed by the consumption of additional working memory capacity can limit recall. Limitations in working memory capacity are also linked to the implementation of higher order process including planning, reviewing and correcting the grammatical errors in writing.

A study by Hooper et al. (2002) supports the link between executive functioning and writing. The study investigated the executive functioning of elementary students with and without written expression problems. Students with writing problems were found
to perform poorly in the initiation and set-shift components of executive functioning. Initiating functions include organisation and planning while set shifting is related to cognitive flexibility and self-monitoring. Finally, limitations in working memory functioning have also been linked to language comprehension.

2.4.4 Working Memory Functioning and Language Comprehension

A theory that relates language comprehension to individual differences in working memory functioning has been developed by Just and Carpenter (1992). It is proposed that during the process of language comprehension information is activated within the working memory system when it is encoded, when it is retrieved from long-term memory or when it is constructed as the immediate or final product of the computations that arise during the processing of the written or spoken text. The role of working memory is not only to store items for later retrieval as the learner constructs ideas from the information contained in the text, but also to oversee the computations that are central to language comprehension itself. In particular, the authors relate syntactic encapsulation, the interaction between syntactic and non-syntactic information during processing and syntactic ambiguity, the ability to activate multiple interpretations of information, to individual differences in working memory capacity.

Research on ambiguity resolution supports the view that individuals with low working memory capacity find syntactically ambiguous sentences difficult to process. While the exact role of working memory in this process has not been resolved, two explanations for this difficulty are identified. The first is that individuals with high working memory capacity are more able to maintain alternative interpretations of a
sentence in working memory. The second is that high capacity individuals are more able to inhibit less preferred interpretations (Fieback, Vos, & Friederici, 2004).

Studies by Mann, Cowin, and Schoenheimer (1989) and Mann et al. (1984) support the link between limitations in phonological component of working memory and difficulties with the comprehension of spoken sentences. It is suggested that ineffective phonetic representations give rise to comprehension difficulties because the phonetic representations in working memory of the words in a lengthy sentence are often insufficient to support full understanding. Limitations in verbal short-term memory have been shown to be involved in the processing of connected discourse whether the information is presented in written or spoken form (Lieberman & Shankweiler, 1985).

In the preceding discussion, individual differences in working memory functioning have been shown to influence language development and the construction of new knowledge by impacting on the learners’ ability to learn and understand the meaning of new words, to hold the content and order of verbal information in memory and to construct new knowledge through the comprehension of both verbal and written information and through writing. The quantity and organisation of the learner’s knowledge base is thought to have a significant influence on knowledge availability and further learning (Ausubel, 1968; Halford, 1998; Muir-Broaddus & Bjorklund, 1990; Novak & Canas, 2006). The nature of the relationship between the construction and storage of knowledge in long-term memory and knowledge availability is now discussed.
2.5 Knowledge Construction and Knowledge Availability

For many years, explanations of the way in which conceptual knowledge is stored in long-term memory were influenced by schema theory. A schema is an organised knowledge structure that provides the basis for the comprehension, learning and remembering of information. According to schema theory, learners are able to comprehend information when they are able to bring to mind schema that can account for objects and events that are contained in new information (Alba & Hasher, 1983; Anderson, 1986). This passive conceptualisation of long-term memory has now been replaced by a more dynamic view (Crebbin, 2002; Easterlin, 1999; Lowery, 1998).

Within this dynamic view of memory, knowledge structures can be assembled to fit current processing demands. Knowledge is described as an associative network where concepts are represented as nodes and relations between concepts as associative links. Individuals differ in the number of concepts available, that is the number of nodes in memory, the organisation of those concepts that is the pattern of associated links, and the accessibility of the information, that is the strength of links between concepts. Schemata are described as groups of associated nodes in the network that are assembled when particular combinations are activated. Nodes are activated depending on the amount of stimulation they receive from incoming information or from other nodes. The system gains flexibility because a node must reach a critical threshold of activation before it can have processing consequences. The updating of the system is described as a process of changing baseline strengths of association as a result of experience. Within this model, long-term memory emerges as a dynamic rather than a passive structure (Garner, 1987; Whitney, 1987).
These explanations of knowledge construction have also been influenced by the integration of research from cognitive science with our growing knowledge of the structures and physiological processes of the brain (Bjorklund, 1997; Easterlin, 1999). Within connectionist explanations, complex processing can emerge when large numbers of units are linked together. A connectionist network has some similarity to the human brain as it also consists of highly interconnected sets of processing units that are composed of neurones. As a result of many experiences during development, patterns of activity emerge within these neural networks and the neural sets form representations of highly complex interconnections of words, objects, events and relationships that can be used to interpret new and familiar experiences. It is the changes in both the structure and complexity of these representations that are considered to be the most significant feature of cognitive development. The quality of the newly constructed knowledge depends on how well the brain is able to organise and store the relationships among the different aspects of the new experience (Lee & Das Gupta, 1995; Lowery, 1998). Research in the area of neuropsychology suggests that memories are not stored in one particular area of the brain but are stored in a number of specifically distributed areas that are interlinked by neuronal connections. When knowledge is recalled, it is reconstructed through a complex reactivation and reconnection process (Crebbin, 2002).

Klein (2006) has used a connectionist view of the process of knowledge construction to describe how language might interact with a connectionist network during conceptual development in science classrooms. In classroom environments that are rich in verbal interaction there is an opportunity for words to become correlated with aspects of experience that form associations in students’ connectionist networks. As a
result of these interactions it is proposed that experiences can form into categories that are distinct from one another.

One study that supports the link between the organisation of the knowledge base and knowledge availability was conducted by Chi and Koeske (1983). The authors evaluated a young child’s knowledge of dinosaurs by mapping this knowledge onto a semantic network. It was proposed that conceptual knowledge is stored as an associative net of nodes and links such that very familiar concepts form a tightly structured highly interrelated organisation. Results were interpreted to suggest that more structured sets of knowledge about dinosaurs were retrieved from long-term memory more easily than less structured sets.

The results of studies that have investigated how previously acquired knowledge can affect further learning indicate that high and low level knowledge structures of individuals influence both the understanding and memory of text knowledge. The ability of high-knowledge individuals to maintain the most important information in working memory is suggested as a reason for differences in task performance (Spilich, Vesonder, Chiesi, & Voss, 1979; Cheisi, Spilich, & Voss, 1979). Prior knowledge has also been shown to impact on the ability to remember and learn new information from text for both good and poor readers (Recht & Leslie, 1988; Lipsom, 1982).

The preceding discussion has described how individual differences in working memory functioning can impact on the quality and quantity of the learner’s knowledge base and how the organisation of this knowledge can influence knowledge
availability and future learning. It has been suggested that if knowledge is readily available it can reduce the demands on working memory capacity during task performance (Muir-Broaddus & Bjorklund, 1990). The relationship between knowledge availability and working memory capacity is now discussed.

2.6 Knowledge Availability and the Capacity of Working Memory

One theory that links working memory capacity to individual differences in knowledge availability is cognitive load theory. Cognitive load theory is a theory of instruction that is based on the assumption that the capacity of working memory is limited and that when instructional activities are designed they should be structured to eliminate any avoidable consumption of working memory capacity. Within this theory, two aspects of knowledge availability have been linked to demand on working memory capacity. The first of these is the degree to which complex schema can be transferred into working memory as a single unit for processing, and the second is the degree to which the knowledge schema that are stored in long-term memory can be retrieved automatically (Kalyuga et al., 1998; Sweller et al., 1998).

Automatic processes have been described by Shiffrin and Schneider (1977) as processes that are not hindered by the capacity limitations of working memory and do not consume attention. The authors use the term control processes to describe limited capacity processes that require attention when they are performed. Examples of control processes include rehearsal, long-term memory search and strategy utilisation. It is thought that one of the benefits of a system that has two basic processing modes is that it allows an individual to engage in increasingly complex modes of processing by building on automatic sub-processes.
Sternberg and Wagner (1982) suggest that many learning difficulties are related to the level of automation of the basic sub-skills that are involved in task performance. This failure of students with learning difficulties to develop automatic processing, results in the need to devote attention to the sub-components of the task and thus consume processing resources that would otherwise be free. When a new task is performed, the functioning of the information processing components consumes a large amount of attentional resources. This controlled processing is regarded as a serial process such that only one set of controlled operations can proceed at one time. In a normally functioning system controlled processing is replaced by automatic processing. Automatic processing is thought to be parallel such that a number of sub-systems can operate at once. It has been suggested that during the performance of a complex task such as reading comprehension, if lower-level processing tasks do not occur quickly enough, active text memories that are involved in the processing task cannot be maintained and difficulties with reading comprehension will occur (LaBerge & Samuels, 1974; Lesgold & Perfetti, 1978; Logan, 1985; Samuels, 1987).

Thus, the complexity and organisation of the learner’s knowledge base has the potential to reduce the capacity demands involved in task performance by influencing the efficiency of mental processing and by influencing how easily the knowledge base can be recalled (Muir-Broaddus & Bjorklund, 1990).

The evidence presented in the preceding discussion suggests that individual differences in the capacity and knowledge availability components of the working memory system can influence the student’s ability to construct new knowledge during
the performance of a complex processing task. An additional factor that has been linked to individual differences in task performance is strategy utilisation. The need to consider the complex interplay between the neurologically-based architecture of the cognitive system and the use of a cognitive strategy, when explaining individual differences in task performance, has been emphasised by Borkowski, Schneider, and Pressley (1989), Campione and Brown (1978), Pressley and Van Meter (1993) and Swanson (1988). The complex nature of this interaction is discussed in the following section.

2.7 The Impact of Working Memory Capacity and Knowledge Availability on Strategy Utilisation

Two terms have been used in the literature to describe individual differences in strategy use. The first is a production deficiency that relates to the individual’s failure to produce a strategy and it is said to relate to the failure of the learner to know what to do (Borkowski et al., 1987). Production deficiencies are related to the inactive view of the learner proposed by Torgensen (1982) and to the suggestion that students who experience difficulty with learning do not spontaneously monitor and regulate their learning, and activate comprehension monitoring strategies only when they have been cued to do so (Bos & Filip, 1984).

However, a study conducted by Gelzheiser, Cort, and Shepherd (1987) found that strategy instruction did not result in the improvement in performance that is predicted by the production-deficient hypothesis of learning difficulty. The authors suggest that factors other than lack of strategy use may account for the poor recall displayed by the
students. This inability of the production-deficient hypothesis to explain why strategy instruction did not lead to an improvement in performance has led to the introduction of a second term, utilisation deficiency to describe the situation where an individual produces the strategy spontaneously but does not acquire a benefit from its use (Waters, 2000).

Pressley and Van Meter (1993) identify the need to understand the individual differences that enable some learners to use strategies efficiently while others achieve little instructional gain. Factors have been linked to efficient strategy utilisation include working memory capacity and knowledge availability. The effect of these factors on strategy utilisation is now discussed.

2.7.1 Strategy Utilisation and Working Memory Capacity

Studies that have investigated the relationship between working memory capacity and strategy utilisation have found that different components or working memory were required for different aspects of task performance. One study that has linked strategy utilisation to both the phonological and executive components of working memory was conducted by Imbo and Vandierendonck (2007). The study investigated the use of executive and phonological working memory resources when adults were required to use simple arithmetic strategies to solve multiplication and division problems. The results of the study indicated that executive working memory resources were required for the direct retrieval of multiplication and division facts and in the use of non-retrieval or procedural strategies such as transformations or counting that used several steps to work out the answer to the multiplication or division fact. Phonological working memory resources were only involved with the use of retrieval strategies. It
was proposed that executive memory resources were used to select the correct response while phonological resources were used for active phonological rehearsal, for the storage of intermediate processing results or for passive phonological storage when more than one number needed to be maintained in short-term memory.

A second study that has related individual differences in working memory capacity to strategy utilisation was conducted by Keeler and Swanson (2001). The relationship between working memory capacity and achievement in mathematics in students with learning difficulties in mathematics was investigated. The results of the study indicated that strategy choices were related to measures of working memory capacity. Students who identified rehearsal as a strategy had higher verbal working memory capacity scores, while students who identified a visuo-spatial strategy had higher visuo-spatial working memory capacity scores than students who chose other strategies.

A third study that investigated the effect of memory capacity on strategy production and strategy effectiveness of kindergarten and first-grade children was conducted by Woody-Dorning and Miller (2001). This study focused on individual differences in working memory capacity rather than group differences. The capacity measures that were similar to the task being investigated were good predictors of task performance. Several of the measures of working memory capacity predicted strategy effectiveness but none were found to be related to strategy production.

In these studies different aspects of working memory capacity have been linked to efficient strategy use. In particular, executive working memory capacity has been
linked to the use of strategies that require a number of procedural steps and to the selection of a correct response (Imbro & Vandierendonck, 2007). This metacognitive view of executive control is related to an information processing view of human memory where a central executive guides the overall functioning of the system (Brown, Bransford, Ferrara & Campione, 1984; Reeve & Brown, 1985) and is similar to the model proposed by Baddeley (2002) where the central executive is described as a limited-capacity, attentional control system with the ability to focus, divide and switch available attention and to maintain information in the service of ongoing cognitive activities such as comprehension and reasoning (Kane et al., 2004).

Brown et al., (1984) have also linked executive control to the concepts of automatic and controlled processing which have been described in section 2.6. The question of how students become aware of their own comprehension failure has been discussed by Markman (1977). The author suggests that while initially it might seem that the realisation that something has not been understood is an automatic process that requires little effort, failure to comprehend could be related to a problem that occurs during constructive processing. In this study, first and third-grade students were given verbally incomplete instructions on how to perform a task. When the instructions were accompanied by student enactment or teacher demonstration of the task, the students were more aware that they failed to understand. It was suggested that the demonstration of the task can provide a partial substitute for the need to form mental inferences relating to the instructions, and that when students enacted the task themselves they were forced into processing the information more deeply. The author concludes that if students fail to realise that something has made sense that this will influence the quality of comprehension itself.
Yore and Treagust (2006) suggest there is a need in science education research to investigate the executive control of the cognitive operations that are central to scientific literacy. Within this view, metacognition is considered to be related to the student’s capacity to use scientific knowledge and is identified as having a central role in controlling the construction of meaning in working memory during the teaching of science.

The second factor that has been linked to effective strategy utilisation is knowledge availability.

2.7.2 Strategy Utilisation and Knowledge Availability

Aspects of knowledge availability that have been linked to strategy utilisation include the availability of domain-specific knowledge, metacognitive knowledge and attributional beliefs (Borkowski, et al., 1987; DeMarie-Dreblow & Miller, 1988; Guttentag, 1984; Muir-Broaddus & Bjorklund, 1990). The impact of each of these factors on strategy utilisation will now be discussed.

2.7.2.1 Strategy Utilisation and Domain-Specific Knowledge

One study that provides an insight into the relationship between domain-specific knowledge and strategy utilization was conducted by Afflerbach (1990). The author investigated how high levels of prior knowledge in anthropology and chemistry influence the use of strategies such as comprehension monitoring, when subjects were required to identify the main idea in a text. Results indicated that prior knowledge had a significant impact on the type of main idea construction strategy used. When the
text was unfamiliar, draft-and-revision and listing construction strategies were most frequently used. However, when the text was familiar, automatic construction of the main idea was more often used. Afflerbach proposed that when experts read familiar topics, well established schema that are more easily accessible were able to be used in the construction task. It was also suggested that deficiencies in other comprehension strategies that are either related to or carried out prior to the main construction task, may interfere with the main idea construction. It was found that the level of prior knowledge influences the efficiency of comprehension processes such as comprehension monitoring and the derivation of word meanings that are necessary for the construction task. These processes tended to consume available capacity such that little capacity was available for the construction task. When the text content was familiar, processes such as comprehension monitoring were performed automatically which allowed for more of the capacity of working memory to be devoted to the construction task. Studies by Kee and Davies (1990) and Rabinowitz (1984) support the view that the accessibility of knowledge may influence how effectively a given organisational strategy is used.

2.7.2.2 Strategy Utilisation and Metacognitive Knowledge

The term metacognitive knowledge is used to describe self-knowledge about cognitive states and processes. When used in this way two broad categories of metacognitive knowledge have been identified. These are self-appraisal of cognition that refers to the current knowledge that an individual knows about a particular domain or task and self-management of thinking that refers to the planning, evaluation and regulation that is required to translate knowledge into action (Reeve & Brown, 1985; Jacobs & Paris, 1987). It is thought that metacognition is responsible
for a student’s initial decision to use a strategy and that this use of metacognitive knowledge results from a developmental process that involves changes to a student’s metamemorial knowledge base over a long period of time during many experiences with strategies (Borkowski et al., 1987).

In particular in the area of science education, Gunstone (1994) describes metacognition in terms of the student’s knowledge, awareness and control of learning. Within this use of the term metacognition each of these aspects of metacognition is considered to be an outcome of learning. The author uses the term enhancing metacognition to describe the development of a student’s more appropriate metacognitive view. A considerable amount of research in the area of science education has been conducted within this conceptualisation of metacognition (Brass, Gunstone, & Fensham, 2004; Case & Gunstone, 2006; Gunstone, 1994; Schraw, Crippen, & Hartley, 2006). For example, a study conducted by Conner (2007) with a group of final-year high school biology students concluded that while most students were aware that the use of strategies to plan, monitor and evaluate could help them to learn more effectively, in general students did not use these metacognitive strategies spontaneously. In this study, those students who used strategies independently produced essays that were of higher quality. It is suggested that by scaffolding students’ awareness of their own learning they can develop metacognitive strategies.

In addition to metamemorial knowledge about a particular domain or task, some models of metacognition have included attributional beliefs to explain why students with learning difficulties fail to use strategies spontaneously (Borkowski, Estrada, Milstead, & Hale, 1989).
2.7.2.3 Strategy Utilisation and Attributional Beliefs

If students attribute their failure to lack of ability and do not develop motivational beliefs that recognise the importance of effort in achieving successful learning outcomes, they often develop low self-esteem which is reflected in a condition referred to as *learned helplessness*. While these students may appear to be indifferent to learning, they are often engaging in self-protective behaviours that are related to their feelings of failure (Borkowski, Weyhing, & Carr, 1988; Borkowski et al., 1989; Garner & Alexander, 1989). A study conducted by Borkowski et al., (1988) concluded that the long-term attributional beliefs of students with learning difficulties were resistant to change. During this study summarisation strategies were modelled, reasons for success or failure were discussed and attributional comments used when the students experienced difficulty with the task. It was concluded that the amount of attributional training needed to produce meaningful change depends on learner characteristics, task difficulty and the availability of strategy knowledge before training.

In the preceding discussion, individual differences in the capacity of working memory and the availability of prior knowledge including domain-specific and metacognitive knowledge have been shown to influence strategy utilisation. The performance of a processing task such as concept mapping requires the smooth coordination of the complex interaction that occurs between these components of the information processing system (Swanson, 1988). For meaningful learning to occur during this process there is a need for the elements of the incoming information to interact simultaneously in working memory with prior knowledge that has been retrieved from
long-term memory (Novak & Canas, 2006; Sweller et al., 1998). One of the assumptions that guided the current study is that when new knowledge structures are being constructed in working memory during complex task performance, the process of knowledge construction needs to be strategically driven (Rabinowitz & McAuley, 1990).

Novak and Canas (2006) state that one of the reasons concept mapping has been used successfully as an aid to the development of meaningful learning is that it provides a scaffold that facilitates the organisation of knowledge during the knowledge construction process. However while concept mapping has proved to be a successful strategy for the development of conceptual understanding, it has been found that a number of students experience difficulty with the process of map construction Chang et al., 2002; Novak & Canas, 2006).

The purpose of the current study was to investigate the nature of the additional scaffolding that might be required to facilitate the process of concept map construction and the development of conceptual understanding in those students who are experiencing difficulty with science learning. In order to gain an insight into the kinds of scaffolding techniques that might be used to facilitate the complex interaction that occurs between the memory and knowledge components of the information processing system during the performance of a concept-mapping task (Borkowski, et al., 1989; Campione & Brown, 1978; Kolligan & Sternberg, 1987; Pressley & Van Meter, 1993; Swanson, 1988), this discussion continues with a review of some of the research that is related to the use of concept maps.
2.8 The Concept-Mapping Process

Concept maps were initially developed as a means of organising conceptual knowledge, from research that began in the 1960s to identify the changes in concept and propositional structures that occurred during children’s conceptual development (Novak et al., 1983; Novak, 2005). These concept maps were two-dimensional hierarchical diagrams that included concepts connected by linking words or phrases that represented the relationship between those concepts. Concepts are described as perceived regulations in events or objects that are represented by a label. Labels are usually words or symbols. Two or more concepts connected by linking words to form a meaningful statement are called propositions (Novak & Canas, 2006). Conceptual understanding is considered to be a reflection of the student’s ability to form relationships between concepts (Romance & Vitale, 1999).

In a review of the research relating to the use of concept maps, Nesbit & Adesope (2006) define concept maps as a type of graphic organiser that consists of labelled nodes denoting concepts, and links that represent relations between concepts. Links are described as being labelled or unlabeled and directional or non-directional. Within this definition, the term concept map includes graphic organisers and knowledge maps. Graphic organisers are described as visual and verbal, spatial displays of the key vocabulary terms contained in a learning task, that use two-dimensional space to represent concept relationships (Moore & Readance, 1984; Katayama & Robinson, 2000). Knowledge maps are described as node-linked representations of knowledge that differ from the concept maps developed by Novak in that they use a common set of pre-constructed labelled links that connect concepts (O’Donnell, Dansereau, & Hall, 2002). In addition, more recent research involving the use of concept maps to
represent student’s conceptual knowledge has evaluated concept maps in a number of different forms. These include spoke, chain and network structures (Chang, 2007; Kinchin, Hay, & Adams, 2000; Williams, 1998).

In the current study, the term concept map is used to represent node-linked assemblies where the links have been labelled using linking words or phrases that represent the relationship between concepts. These links have not been pre-constructed for the student. However the term has been used to include spoke, chain and network structures that differ from original hierarchical conception of concept maps described by Novak & Canas (2006).

Concept maps have been used in science research in two ways. Firstly, as an evaluative tool that can be used to represent and monitor a learner’s conceptual knowledge (Allchin, 2002; Daley et al., 1999; Martin, Mintzes, & Clavijo, 2000; Quinn, Mintzes, & Laws, 2003) and secondly, as a strategy that can be used to facilitate the development of conceptual understanding (Blankenship, Ayres, & Langone, 2005; Guastello, Beasley, & Sinatra, 2000; Stoyanova & Kommers, 2002; Sturm & Rankin-Erickson, 2002; Van Boxtel et al., 2002). In the current study, concept maps were used to perform each of these functions. Each of these uses of concept maps is now discussed.

2.8.1 Concept maps as an evaluative tool

In general, studies that have used concept maps as a tool to evaluate a learner’s current state of conceptual development have used two methods of evaluation. These are quantitative methods, that make a count of certain map characteristics such as
concepts, concept links and hierarchies (Mintzes & Wandersee, 1998, Novak, 2005; Rye & Rubba, 2002; West, Pomeroy, Park, Gerstenbergen, & Sandoval, 2000) and qualitative methods, that describe the individual differences in the content, structure and quality of the student’s concept maps (Hay, 2007; Kinchin, et al., 2000; Van Zele, Lenaerts, & Weime, 2004; Williams, 1998).

One example of a study that used a quantitative method to evaluate conceptual knowledge in science was conducted by Martin et al. (2000). The study was conducted with a group of university biology students over a period of a semester. In this study two methods of scoring concept maps were used. The first method scored maps for structural complexity and propositional validity and awarded points for concepts, relationships, hierarchy, branching, cross-links and interconnectedness. Using this method, hierarchy and cross-links were rated at five and ten points respectively whereas concepts and relationships were rated at one point each. The second method identified the frequency of structural change in the student’s concept maps. A second component of this study used clinical interviews that were designed to encourage students to reflect on their learning and to evaluate their own performance. Analysis of these interviews identified study participants as either rote or meaningful learners. Those students identified as meaningful learners were found to have a stronger ability to monitor and control their learning. While the main evaluation method that was used in this study relied on the quantitative evaluation of map structure, it also draws attention to the fact that additional means of evaluation such as clinical interviews and a consideration of the structural changes in concepts maps can also be useful in providing additional information about the learner’s current level of conceptual development.
Prompted by concerns about the validity and reliability of concept map scoring systems, some researchers have begun to investigate alternative means of allocating points to the different components of the concept maps. A study conducted by Rye and Rubba (2002) investigated a method that emphasised the use of two aspects of students’ concept maps. These were concepts and propositions. Propositions were given greater weight than concepts as they were considered to provide a more accurate measure of students’ understanding. Levels of branching and concept hierarchy were not given a score. In this study, students’ map scores that emphasised concept relationships were found to correlate highly with students’ performance on standardised tests. This study highlights the significance of student-constructed propositions as a means of tracking the development of conceptual understanding.

The importance of student-constructed propositions in the evaluation of conceptual development has also been identified by Williams (1998). In this study, concept maps were used to evaluate the conceptual knowledge of university students who were enrolled in a calculus class. While the student-constructed concept maps that were drawn in this study were evaluated using an expert map, it was decided that because the students’ individual concept maps reflected widely divergent understanding of the main concepts, that these maps did not warrant evaluation using a numerical scoring system. Individual differences in the propositions that students used to construct the concept maps were found to reveal a detailed insight into their understanding of specific concepts.
The studies conducted by Rye and Rubba (2002) and Williams (1998) not only highlight the value of concept maps as a means of evaluating conceptual development, but also provide support for the suggestion that the formulation of propositions is an essential means of representing students’ understanding (Fensham, Garrard, & West, 1982; Novak & Canas, 2006). While quantitative methods of concept map analysis can be used to provide numerical information about individual differences in the structural complexity and propositional validity of the elements of the map, they do not provide the level of insight that can be gained from a detailed qualitative analysis of individual differences in map characteristics.

One study that provides an insight into the ways in which students’ concept maps reflect development of conceptual knowledge was conducted by Hay (2007). In this study, three descriptions of concept analysis that are related to the changes that occur in students’ knowledge structures during learning are identified. These include deep learning, surface learning and non-learning. Deep learning is characterised by a progression in concept development that reflects the appearance of newly learnt concepts, the meaningful linkage of new knowledge to prior knowledge and an overall improvement in the organisation, linkage and clarity of propositions from one map to the next. Surface learning is characterised by an increase in the number of new concepts but these concept are not integrated in a meaningful way on the map. Non-learning is characterised by the absence of new concepts and meaningful linkages from one map to the next. Student’s individual concept maps are presented and analysed to provide evidence of the changes that occurred in the student’s knowledge structures.
A second study that used the structure of students’ concept maps to analyse patterns of conceptual development was conducted by Kinchin et al. (2000). In this study, the concept maps produced by Year 8 science students were analysed. Three concept map structures were identified. These were a spoke, that was a radial structure in which all of the secondary concepts were linked to the core concept but not to each other; a chain, that was a linear sequence where each concept was linked to the one above and below; and a net, that was a highly-integrated, hierarchical, conceptual network. Within this system of map identification, concept maps are analysed in terms of hierarchy, processes, complexity and conceptual development. Correct links are considered to be as important as incorrect links as they have the potential to increase teacher awareness of students’ misconceptions. The authors suggest that these three concept map structures may represent progressive levels of conceptual knowledge development, and that an awareness of these developmental conceptual pathways may lead to the selection and sequencing of teaching materials that promote more meaningful learning outcomes.

The preceding discussion identified a number of ways in which concept maps can be used to evaluate conceptual knowledge development. The benefits of using qualitative methods of evaluation to identify individual differences in conceptual understanding have been highlighted. In particular, the studies conducted by Kinchin et al. (2000) and Hay (2007) support the suggestion that concept maps can be used as an active component of the teaching and learning process that can be used throughout the curriculum (Fensham et al., 1981; Quinn et al., 2003). In addition to their use as an evaluative tool, concept maps have also been used as a tool to facilitate the development of conceptual knowledge (Novak & Canas, 2006).
2.8.2 Using concept maps to promote conceptual development

Studies that have used concept maps as a tool to foster the development of conceptual knowledge have involved the use of student-centred small-group collaboration (Stoyanova & Kommers, 2002; Van Boxtel et al., 2002), teacher-directed whole class and small group collaboration (Guastello et al., 2000) and computer-supported concept map construction (Blankenship et al., 2005; Stoyanova & Kommers, 2002; Sturm & Rankin-Erickson, 2002).

One study that used student-centred small-group collaborative concept mapping to investigate the process of knowledge construction was conducted by Van Boxtel et al. (2002). In this study pairs of students constructed hand-drawn concept maps in their secondary physics classes. The authors suggested that the interactions that occurred between students during the process of map construction required them to be actively involved not only in reflecting and elaborating on their own understanding, but also to be actively involved in integrating and elaborating on the understanding of others. In addition, the concept maps provided a visual representation of their ideas that could be used to facilitate communication about concepts. Students could use the concepts and propositions on the developing concept map to assist their verbalisation of ideas and their negotiation of meaning. It was concluded that the collaborative construction of the concept maps resulted in deeper processing of information by enabling students to discuss the meanings and relationships between concepts, to elaborate their conceptual knowledge and to co-construct meaning. Some of the limitations of this form of collaborative concept mapping were that the students’ discourse rarely reached the explanatory level, and that the students did not engage in conversations...
that clarified common science misconceptions. In order to overcome these difficulties additional representational tasks, such as writing, were provided that required students to elaborate further on the conceptual relationships identified in the concept map. Studies that have used teacher-directed collaborative concept mapping have been found to provide a solution to some of these difficulties.

One example of a study that used teacher-led collaborative concept mapping to investigate the reading comprehension of a group of low achieving seventh-grade students when they studied a chapter of a science text was conducted by Guastello et al. (2000). In this study, two teaching methods were used. One group of students was taught using a teacher-directed method where students participated in a teacher-directed lesson followed by teacher-guided reading of the text chapter. No visual reinforcement other than the text was provided to this group. The second group of students completed the same introductory lesson however, when this group read through the text with the teacher, they constructed a concept map as they engaged in discussion with the teacher. The results of the study indicated that graphic representation of information was more effective than traditional instructional techniques in improving the comprehension of low achieving students.

A further benefit of the use of teacher-led collaborative concept mapping is to encourage students to evaluate their own learning. A study conducted by Daley et al., (1999) used concept maps to assist a group of nursing students to develop self-appraisal of their own thinking processes. The use of concept maps in post-mapping discussion groups gave educators and students the opportunity to discuss conceptual relationships and to clarify misconceptions that had been represented in the students’
concept maps. A second study in which concept maps were used as a tool to foster self-evaluation was conducted by Mok, Lung, Cheng, Cheung, & Ng (2006). In this study, concept maps were used to provide a template for the representation of knowledge relating to teacher education in conjunction with a strategy referred to as the Know-Learn-Want method, to encourage students to self-assess their learning progress.

A study conducted by Stoyanova & Kommers (2002) used concept mapping as a medium for the implementation of computer-supported collaborative problem solving. Concept mapping was considered to be an effective strategy to facilitate collaboration as it externalises the cognitive structures of the students, it clearly identifies the meanings of concepts and ideas and it allows students to visualise the whole problem space. In this study, three collaborative situations were investigated. These included distributed interaction, where students constructed concept maps independently which were then passed on to other members of the group until all members of the group come to a common understanding of the problem; moderated interaction, where the interactions of the group are facilitated by a group moderator who adjusts the individually produced maps until a common vision is reached and a shared interaction, where group members interact directly to share their knowledge. The results of the investigation indicated that shared interaction was the most effective in collaborative problem solving. It was concluded that one of the factors that influenced the effectiveness of the collaboration process was the way in which students share not only the results but also the process of knowledge acquisition.
An essential component of the shared interaction intervention described by Stoyanova & Kommers (2002) is the use of computers to facilitate the knowledge construction process. Scardamalia and Bereiter (1993) support the use of computer-assisted individualised instruction, as a means of altering classroom discourse so that students come to see themselves not as simply the passive recipients of knowledge but also as the active constructors of knowledge who can refine their ideas through interaction with others.

One study that identifies some additional benefits associated with the use of computer-generated concept maps was conducted by Sturm and Rankin-Erickson (2002). This study investigated the effect of computer-generated and hand-drawn concept mapping on the descriptive essay writing on a group of year-eight students who were identified as needing reading support. In this study, attitude to writing was also examined. The results of the study indicated that students’ descriptive essays produced in the computer-generated and hand-drawn concept mapping conditions produced significant increases in holistic writing scores above the baseline writing samples. While the results of the study did not clearly support the benefits of either form concept mapping when writing samples were analysed, the results showed that students’ attitude to writing was more positive in the computer-mapping condition.

A study conducted by Blankenship et al. (2005) investigated the impact of a computer-based cognitive mapping on the reading comprehension of content material of three fifteen-year-old students with emotional behaviour disorders. Students used the computer program Inspiration to construct concept maps independently, as they read through a history text. The results of the study indicated that all of the students
who had previously experienced difficulty in engaging in independent learning activities used concept mapping to improve their comprehension of the content information in the history text. The teacher who implemented the study reported that the use of the computer-based program was well received by the students and that the students who were previously dependent of teacher-led instruction to control off-task behaviour worked more independently after the software was introduced. In order to track student progress during this study, the teacher required the students to answer a number of probe questions. If they did not answer these questions correctly the students were not given feedback from the teacher but were required to go back and re-read the text. The researchers reported that the students found this lack of teacher feedback frustrating and suggest that future research might consider some form of interaction between the teacher and the students to provide the students with feedback about the content of their concept maps.

In addition to studies that have used collaborative dialogue and computer-generated concept maps to facilitate the concept-mapping process, a study conducted by Chang et al. (2001) used a computer-based mapping system to provide additional visual scaffolding to the concept mapping process. The effect of construct-by-self, construct-on-scaffold and construct-by-paper-and-pencil concept mapping on learning outcomes in Biology was evaluated. The construct-by-self version required students to construct concept maps using a computer-based mapping system without the use of a scaffolding aid. In the construct-on-scaffold version the computer program provided a scaffold that was an incomplete framework of an expert concept map with some blank nodes and links. The students were provided with a list that contained all of the concepts and links to be used. While the construct-on-scaffold concept map had the
most significant effect on learning, each of the computer-based concept mapping systems was found to benefit students in completing their concept maps.

In a second study, Chang et al. (2002) used samples of expository text from the science and social science domains to investigate the impact of three concept-mapping approaches on the reading comprehension of fifth-grade students. The three concept-mapping approaches included map correction, where students were provided with an expert-generated concept map that had been partially revised to contain incorrect concept and links; scaffold fading, where there was a gradual reduction in the level of scaffolding provided, from the provision of an expert-generated concept map to a situation where the students were given only the text; and map generation, where only the text was provided. In this study, feedback was provided using the computer mapping system. The map-correction group received the percentage of their corrections that were correct as feedback. The map-generation group received the percentage of their correct choice of key concepts and links compared to the concept and link list that was provided, and also a measure of the level of completion of their concept map, as feedback. The scaffolding-fading group received feedback using the percentage of correctly filled in blanks and the same feedback that was provided to the map-generation group. The results of the study revealed that the map-correction group demonstrated the greatest improvement in text comprehension. During the study students’ comments indicated that they had found concept mapping difficult in both the map-generation group and the scaffold-fading group once the scaffold was removed. Chang et al. (2002) suggest working memory capacity as a factor that may be related to these difficulties with concept map construction and with the fact that these groups did not achieve the desired learning outcomes.
In each of these studies outlined above, the construction of the concept maps themselves provided a scaffold for the knowledge construction process (Novak & Canas, 2006). As well, additional levels of scaffolding were provided during the construction of the concept maps using the following techniques:

1. The use of student dialogue to encourage elaborative processing (Van Boxtel et al., 2002).
2. The use of teacher-directed discussion to provide expert feedback regarding students’ misconceptions and to encourage self-evaluation (Daley et al., 1999; Mok et al., 2006).
3. The use computer-supported concept mapping to foster student motivation and task persistence (Blankenship et al., 2005; Sturm & Rankin-Erickson, 2002).
4. The use of computer-constructed visual scaffolds to increase elaborative processing and reduce the cognitive load on working memory (Chang et al., 2001; Chang et al., 2002; Stoyanova & Koomers, 2002).

However, in addition to the identification of a number of techniques that provided additional scaffolding to aid the process of concept map construction, a number of limitations associated with the ways in which scaffolding was provided were identified. These limitations related to the manner in which corrective feedback and additional practice were provided. For example, the study conducted by Van Boxtel et al. (2002) relied solely on student interaction to facilitate conceptual development. It was noted that the conversations between pairs of students did not engage students in concept clarification nor did they enable students to clarify misconceptions. Elaborative activities such as writing were recommended to provide additional
practice to aid concept clarification. Blankenship et al. (2005) recommended the use of teacher explanation as a means of providing students with feedback about the appropriate material to include in their concept map.

One form of instruction where the teacher deliberately models and activates the knowledge and processes that are required for successful learning is explicit teaching (Cambourne, 1999). While this form of instruction has been derived mainly from reading and mathematics research, it can be applied to the teaching of any subject area including science that requires the mastery of a body of facts and concepts. Explicit instruction scaffolds knowledge construction by introducing new material in small steps, by providing teacher guidance during initial practice and through the provision of sufficient additional practice until the processing of new information becomes automatic (Rosenshine, 1986; Yore & Treagust, 2006).

Hudson, Miller, and Butler (2006) describe four phases that identify an explicit teaching sequence. These are an advance organiser that activates prior knowledge, a teacher demonstration where the teacher models the thinking processes that are required for task completion, guided practice where the teacher verbally supports the student during task completion and lastly independent practice using a variety of material such as work sheets and peer tutoring. Questioning and discussion are considered to be key features of the instructional process.

Similarly, Gillis, and MacDougall (2007) identify the pre-active, interactive and reflective phases of a learning cycle to describe how students can be actively engaged in thinking, reading, talking and writing about science while reading a science text.
During the pre-active phase the learner’s level of prior knowledge is activated through the use of strategies such as graphic organisers. The interactive phase is designed to enhance the level of teacher-student interaction that improves the student’s comprehension of the text. Strategies such as concept-map completion, thinking aloud and question generation could be used in this phase of the cycle. During the reflective phase students are encouraged to discuss and write about scientific concepts to develop their scientific knowledge. Within this explicit teaching framework, the process of concept map construction is supported by a variety of instructional techniques that provided additional opportunity for the construction and elaboration of the student’s knowledge networks. These include the consolidation of prior knowledge using graphic organisers to introduce new vocabulary, the use of interactive dialogue and writing to provide regular opportunities for feedback and practice that aid knowledge restructuring and a reduction of task complexity by presenting the instructional materials in smaller more manageable steps.

The way in which each of these instructional techniques could be used to scaffold the process of concept map construction is now discussed.

2.9 Instructional Techniques used to Scaffold the Concept-Mapping Process

2.9.1 Graphic Organisers

Graphic organisers are visual and verbal spatial displays of the key vocabulary terms contained in a learning task that use two dimensional space to represent concept
relationships (Moore & Readence, 1984; Katayama & Robinson, 2000; Robinson, Katayama, Dubois, & Devaney, 1998).

One way in which schematic diagrams such as graphic organisers may enhance the processing of information through the working memory system has been suggested by Marcus, Cooper, and Sweller (1996). The authors investigated the use of schematic diagrams to reduce the cognitive load associated with the understanding of instructions that were related to a science task. The findings of the study suggested that difficulties with understanding are not related to the amount of information that is contained in the instruction, but to the amount of information that needs to be held simultaneously in working memory. It is suggested that if the interacting elements of information can be incorporated into a diagrammatic schema it may be possible for the entire set of connections to be processed as one single unit and as a result reduce the working memory load.

A second way in which diagrams such as graphic organisers may enhance the processing of information through the working memory system is by the dual processing of information (Gerlic & Jausovec, 1999; Katayama & Robinson, 2000; Romance & Vitale, 1999). Because the model of working memory proposed by Baddeley (2002) included verbal and visuo-spatial short-term memory components that have separate memory capacities, the construction of graphic organisers in conjunction with semantically equivalent text may enhance the representation of both verbal and visuo-spatial information in working memory and as a result, simultaneous verbal and visuo-spatial processing can be performed efficiently without overloading the working memory system (Nesbit & Adesope, 2006; Sweller et al., 1998).
The benefits of the use of varied forms of rehearsal have been identified by McNeal and Dwyer (1999). Firstly, the longer that incoming information is maintained in working memory, the more effectively it can be elaborated upon and transferred to the long-term memory store. Secondly, different rehearsal processes may allow for information to be processed simultaneously on different levels resulting in a different intensity of learner involvement in more complex learning tasks. When designing interventions for students with learning difficulties, Pressley, Johnson and Symons (1987) recommend the use of a variety of elaborative components that foster the formation of additional representations of information in memory. In addition to the enhanced rehearsal that is provided by the encoding of information through both the verbal and visuo-spatial channel, the introduction of the episodic buffer as a fourth component of the working memory system (Baddeley, 2002), has provided a site where information from the phonological loop and the visuo-spatial sketchpad can be integrated to form a multi-modal code (Reed, 2006).

Research in the area of reading also supports the suggestion that the difficulties that some students experience with the processing of verbal information can be overcome through the use of visual information. In a study by Katz, Schankweiler, and Lieberman (1981), subjects were presented with two sets of drawings. The first consisted of nonsense drawings that could not easily be recoded phonetically in short-term memory, while a second set of drawings could easily be recoded as words and stored in phonetic form. Results indicated that performance differences between good and poor readers were not significant when they were asked to order stimuli that were difficult to label, but a significant difference was found between good and poor
readers when they were required to order stimuli that could be recoded easily. The authors concluded that good readers are better able to make use of phonetic codes in working memory.

This difference between the recall of verbal and visual information is also supported in a study by Liberman, Mann, Shankweiler, and Werfelman (1982). The performance of good and poor second grade readers was investigated on three different memory tasks. These were nonsense designs, photographs of unfamiliar faces and printed consonant-vowel-consonant nonsense syllables. The results indicated that poor readers performed as well as good readers when asked to remember both nonsense designs and faces. However, poor readers made significantly more errors when recognising nonsense syllables. It was suggested that the difficulties relating to remembering language-based material were linked to the phonetic representation of information in short-term memory.

There is also some evidence to suggest that the use of visual material can improve comprehension performance. A study by Shankweiler, Smith, and Mann (1984) assessed the comprehension of good and poor readers on verbal and picture tasks. Good and poor readers differed significantly on the verbal recall task but not in comprehension when it was assessed by the picture task. It was suggested that the use of pictures provided cues that reduced memory load. A second study by McNeal and Dwyer (1999) investigated the effect of different rehearsal strategies on student achievement in science. Four instructional treatments were assessed. These were text based instruction alone, text based instruction with questions on the content, text based instruction with visuals and text based instruction with questions and visuals.
The text based instruction with questions and visuals resulted in higher achievement scores. It was suggested that the combination of verbal and visual processing allowed the information to be processed more deeply.

A second instructional technique that can be used to facilitate the construction and elaboration of students’ knowledge networks is the use of interactive dialogue.

2.9.2 Interactive dialogue

The critical role played by dialogue in scaffolding instruction has been described by Palincsar (1986). The distinguishing features of dialogues that promoted effective scaffolded instruction included the degree to which teachers supported the students’ contribution to the dialogue at the conceptual level, the degree to which students’ ideas were linked to new knowledge, and the degree to which the point of the instruction was made explicit by the teacher. The way in which evaluative statements were phrased had an impact on the way students responded.

Roehler and Duffy (1986) describe how cognitive development can be fostered through interactive dialogues between the teacher and the learner. As the instructional message of the teacher-student dialogue is delivered the information converts to the students’ inner speech that then helps to organise the students’ internal thought processes. Mental functions are represented initially in social dialogues on the interpersonal plane and then, when learning has occurred, as part of the students’ internal mental function on an intra-psychological plane. Vygotsky (1962) explains that it would be wrong to regard thought and speech as two unrelated processes. In the work of Vygotsky two planes of speech are identified. These are inner semantic
speech and external phonetic speech. Children’s ability to communicate is directly related to their ability to differentiate word meanings in consciousness. In order to understand the relationship between thought and word there is a need for a clear understanding of the nature of inner speech. Vygotsky suggests that the function of inner speech is directly connected to the child’s thinking. Its main distinguishing feature is its peculiar syntax, which when compared to external speech, appears to be disconnected and incomplete. With syntax and sound reduced to a minimum, inner speech works with semantics not phonics. In the process of inner speech words fade as they bring forth thought as pure meaning. Baddeley (2002) suggests an additional role for the phonological loop component of working memory that is similar to the notion of inner speech described by Vygotsky.

A number of teaching practices have been designed to highlight the specific nature of instructional dialogues. Duffy, Roehler, and Herrmann (1988) describe a teaching technique called mental modelling that informs students about the flexible reasoning processes that underlie strategic reading. The authors believe that failure to make reasoning processes explicit leaves poor readers in doubt about how expert readers make sense out of the text. They also suggest that for the instructional sequence to be effective students must be given an opportunity to express their understanding of the task. The authors believe that mental modelling must be incorporated with interactive teacher-students’ dialogue to ensure that students do not misinterpret the mental modelling and as a result, develop misconceptions.

Details of interactive student-teacher dialogues that aim to improve instruction through the use of responsive elaboration have been described by Duffy and Roehler.
The authors state that because all students do not understand the teacher’s explanation in the same way at the same time, explanation needs to continue during the interactions that follow modelling. Two important features of these interactions are identified. The first of these is assessment, where the teacher observes students’ reasoning to infer what they understand about how to carry out the mental processing associated with the use of the strategy. If students’ responses reveal a lack of understanding, the teacher uses the second feature of responsive elaboration; more explanation. This type of instructional intervention is described as responsive because it requires the teacher to use statements of student reasoning to decide how to respond in the next interactive cycle. It is elaboration because it is not a new explanation but an elaboration of the original explanation. The authors believe that teachers may find responsive elaboration difficult for two reasons. Firstly, because it requires teachers to be extremely sensitive to what students are saying so they may infer what their responses indicate about their mental acts. Secondly, after assessment the teacher is required to do more than provide feedback about the correctness of the response or ask a series of questions. Instead the teacher needs to provide the students with information with which they can construct an understanding of how to reason when using strategies. This technique requires the teacher to be a skilful appraiser, moving the level of support as the student’s performance suggests. Scott (1998) states that in science classrooms, the specific nature of responsive teacher talk can be broken down into three elements. These are establishing the initial performance of the student, identifying any discrepancies between current and desired performance levels and then responding with an appropriate dialogue intervention that will support student learning.
A third instructional technique that can be used to facilitate the construction and elaboration of students’ knowledge networks is the use of writing.

2.9.3 Writing

Studies conducted by Gunel, Hand, and Prain (2007) and Hand, Hohenshell, and Prain (2007) support the use of writing as a learning tool in science classrooms. Writing can be used in science classrooms not only as a recoding and assessment tool but as a means of drawing on prior knowledge to prepare students for new learning, of fostering conceptual understanding, of clarifying misconceptions, of encouraging students to become more active learners so that they will reflect on their current level of understanding, and of providing a visual representation that is available for immediate review (Abell, 2006; Baker, Barstack, Clark, Hull, Goodman et al., 2008; Knipper & Duggan, 2006; Meiers & Knight, 2007). Abell (2006) suggests that if the purpose of writing is to build conceptual understanding in science then teachers should expect clarity in students’ explanations and should not accept a single word as a substitute for an expression of conceptual understanding. A number of teacher responses to students’ writing are suggested. These include engaging students in writing tasks that go beyond recording and summarising, assisting students to structure their writing and providing direct feedback about their current ideas. The essential role of corrective feedback for learning is supported by Viadero (2006). The author also reports on research that suggests that learning seems to be more effective when students are required to develop their own written answers to questions, word definitions or concepts.
A study by Syh-Jong (2007) examined the combined effect of talk and writing on the construction of students’ science knowledge in collaborative group settings. By writing and speaking in a collaborative group, students were required to make their conceptual understanding more explicit and in this way they became more active learners. It was found that writing and speaking in collaborative groups complemented each other and facilitated students’ construction of knowledge. Writing helped students to construct knowledge clearly, while talking helped them to make explicit the meaning of the information that was implicit in their writing.

Finally, the presentation of instructional materials in more manageable steps has been used to facilitate the construction and elaboration of students’ knowledge networks.

2.9.4 Presenting Instructional Materials in More Manageable Steps

When teaching new or difficult material it is important to break the task down into smaller steps in order to overcome the problems associated with overloading the working memory system (Rosenshine, 1986). By presenting too much information at one time during the process of instruction, the capacity of working memory is exceeded and the effectiveness of the instruction will be decreased (Kalyuga et al., 1998). One means of reducing the cognitive load associated with complex processing tasks is to provide learners with a partial solution to the problem (Sweller et al., 1998).

One study that has investigated the effect of reducing the cognitive load associated with the processing of instructional materials by providing partial solutions was conducted by Katayama and Robinson (2000). Undergraduate students were
provided with complete, partially-complete and skeletal graphic organisers and outline notes while they studied a textbook chapter. No differences were observed on the factual test for any of the six study conditions. However, on the application test those students who completed the partial notes with approximately half of the information supplied, outperformed those students who used the complete or skeletal outline notes. It was suggested that completing partial notes proved to be advantageous as the students benefited from encoding advantages that resulted when they were actively involved in the note taking process and when they were not overwhelmed by the high cognitive load of the task. The use of graphic organisers proved to be more effective than outlines in providing these benefits.

2.10 Summary and Implications for the Current Study

In this chapter concept mapping has been identified as a teaching and learning strategy that has been used in science education to facilitate the development of conceptual knowledge (Novak & Canas, 2006). The chapter outlined a model of working memory that can be used to explain how individual differences in working memory functioning can impact on the process of knowledge construction and strategy utilisation.

When students use a concept mapping strategy to facilitate the development of conceptual knowledge while summarising a chapter of a science text, they are required to identify the factual knowledge contained in the text, to evaluate this knowledge in terms of what they already know and then to link these concepts to form a meaningful whole on the concept map (Guastello et al., 2000). In this chapter it has been suggested that one of the reasons that some students experience difficulty with
the process of concept map construction is that they have limitations in the functioning of some of the components of their working memory system (Cornoldi et al., 2001; Gathercole & Baddeley, 1989; Gathercole & Pickering, 2000; Swanson & Sachse-Lee, 2001b) that impact not only on the number of concepts and propositions that can be processed simultaneously in working memory (Just & Carpenter, 1992; Lieberman & Shankweiler, 1985; Novak & Canas, 2006) but also on the storage and availability of conceptual knowledge in long-term memory (Cain et al, 2004; Chi & Koeske, 1983; Gathercole, 1990; Katz, 1986). It is also suggested that the combination of these two factors restricts the smooth flow of information through the working memory system when new knowledge is constructed (Kolligan & Sternberg, 1987; Swanson, 1988) and as a result limits the effective use of a concept mapping strategy. Additional factors that have been linked to the effective use of a concept mapping strategy include metamemorial knowledge (Borkowski et al., 1987; Conner, 2007) and attributional beliefs (Borkowski et al., 1988; Garner & Alexander, 1989).

In the current study it was proposed that by scaffolding the concept-mapping process, the flow of information through working memory could be enhanced, and as a result reduce cognitive load (Kalyuga et al., 1998; Sweller et al., 1998) and facilitate the development of conceptual knowledge during the process of concept map construction. Specifically, the study aimed to investigate the impact of verbal and visuo-spatial scaffolding activities on the development of conceptual knowledge when students who experience difficulty with science learning used concept mapping to summarise a chapter of a science text. The study also sought to establish whether some of the students who are experiencing difficulty with science learning have
individual differences in their working memory functioning and to investigate how such individual differences might influence the type of scaffolding that was required.

The investigation of impact of scaffolding activities on the development of conceptual knowledge during the process of concept map construction was guided by the following assumptions.

1. That the process of new knowledge construction needs to be strategically driven (Rabinowitz & Macaulay, 1990).
2. That working memory is the site of new knowledge construction during the concept-mapping process (Novak & Canas, 2006).
3. That the episodic buffer is the component of the working memory system where the active process of knowledge construction takes place. Within the episodic buffer, knowledge that has been activated from long-term memory interacts with incoming verbal and visuo-spatial information, under the control of the central executive, to form a new knowledge structure (Baddeley, 2002).
4. That working memory consists of domain-specific and domain-general storage and processing components each of which has an individual functioning capacity (Baddeley, 2002; Bayliss et al., 2003; Pickering, 2006; Swanson, 1994; Swanson & Sachse-Lee, 2001a).
5. That strategy utilisation can be influenced by individual differences in working memory capacity (Keeler & Swanson, 2001; Woody-Dorning & Miller, 2001) and knowledge availability including domain specific knowledge (Afflerbach, 1990; Kee & Davis, 1990; Rabinowitz, 1984),
metamemorial knowledge (Borkowski et al., 1987; Conner, 2007) and attributional beliefs (Borkowski et al., 1988; Garner & Alexander, 1989).

6. That during the performance of concept-mapping task, there is a need for the smooth coordination of functioning of the knowledge, strategy, memory and metacognitive components of the information processing system to ensure successful task performance (Kolligan & Sternberg, 1987; Swanson, 1988).

The current study differed from previous studies that have investigated the use of concept mapping to facilitate conceptual knowledge development in a number of ways. The first was the way in which individual differences were investigated. While some previous studies have proposed that limitations in working memory capacity impede the process of concept map construction (Chang et al., 2001; Chang et al., 2002; Katayama & Robinson, 2000) they did not investigate individual differences in the working memory functioning of the students who participated in the studies. In addition, previous studies that have investigated the impact of individual differences in learning characteristics such as prior knowledge and verbal ability on the learning that resulted from the use of concept maps, only used non-standardised assessments to identify the nature of the individual differences that were investigated (Nesbit & Adescope, 2006). Also, students were not observed individually while they constructed the concept maps (Chang et al., 2002; Nesbit & Adescope, 2006).

In the current study, individual differences in students’ working memory functioning were identified using standardised assessment measures and these individual differences were taken into consideration during the design, evaluation and redesign stages of the scaffolding intervention. In addition to the assessment of individual
differences in students’ working memory functioning, the students who participated in
the current study were observed individually while they were constructing concept
maps. These individually-constructed concept maps were evaluated using quantitative
techniques that considered changes in the overall structure and complexity of the
conceptual knowledge represented in the concept maps (Hay, 2007; Kinchin et al.,
2000).

A second feature of the current study was the manner in which corrective feedback
was provided. In the study conducted by Chang et al., (2002) the corrective feedback
relating to the accuracy of the students’ concept maps was provided using computer-
generated feedback. While the study conducted by Van Boxtel et al., (2002) identified
the benefits of collaborative student dialogue, a number of disadvantages associated
with student-centred interaction were also identified. These disadvantages related to
the fact that the students’ discourse rarely reached the explanatory level and that the
students did not engage in conversations that clarified common science
misconceptions. Studies that included the use of teacher-led discussion identified the
benefits of using teacher-student dialogue in clarifying conceptual knowledge, in
identifying misconceptions and in promoting self-evaluation (Guastello et al., 2000).
In the current study corrective feedback was provided by the researcher and learning
support teacher aides using responsive elaboration (Duffy & Roehler, 1987) and
mental modelling (Duffy et al., 1988).

A third feature of the current study was that the concept maps constructed and
evaluated during the study were student-constructed node-linked structures, where the
links were labelled using linking words or phrases. This is in contrast to previous
studies that had used concept mapping to investigate knowledge development in which the links used in the process of concept map construction were pre-constructed (Chang et al., 2002; O’Donnell et al., 2002) or in which links were not required to be formulated by the students (Boyle, 1996). O’Donnell et al. (2002) suggest that one of the benefits of using knowledge maps with students of low verbal ability is that there is a reduction in processing load because of the limited vocabulary and simplified grammar that is associated with the use of pre-constructed links on the knowledge maps. However, since linking words are considered to represent the student’s understanding of the relationship between the concepts (Novak & Canas, 2006; White & Gunstone, 1992), in the current study, requiring the students’ to construct the propositions on the concept map was considered to be an essential part of the current investigation into conceptual knowledge development.

Fourthly, in contrast to the studies conducted by Boyle (1996) and Chang et al. (2002) that used short reading passages, the instructional texts used in the current study were the textbook chapters contained in the students’ science texts. These texts reflect the level of language complexity that middle school students are required to read and evaluate to develop scientific literacy. One of the difficulties associated with science learning in the secondary school is the complexity of the language used in challenging, high-content expository texts (Baker et al., 2002; Gajria et al., 2007). Some of the features that make science texts difficult to interpret include the use of technical vocabulary and complex sentence structures (Fang, 2006). Given that one of the central aims of scientific literacy is that all students develop the ability to read and evaluate science texts (Millar, 2006), it is important to investigate the effectiveness of
the use of comprehension strategies such as concept mapping using real science texts (Gajria et al., 2007).

The research methodology and methods that were used to investigate the individual differences in working memory functioning of students who experience difficulty with science learning and to guide the development and evaluation of the instructional sequences that were used to scaffold the concept-mapping process are outlined in Chapter 3.
CHAPTER 3

Study Methodology and Methods

The central aim of the current study was to investigate the impact of scaffolded concept mapping on the development and representation of conceptual knowledge in students who are experiencing difficulty with science learning. In Chapter 2, a number of factors that have the potential to impact on the development and representation of conceptual knowledge have been identified. These include working memory capacity and knowledge availability including domain-specific and metacognitive knowledge. It was proposed that some of the students who experience difficulty with science learning have working memory profiles that identify individual differences in working memory capacity, and that these differences in working memory functioning can impact on of the smooth coordination of the memory, knowledge and strategy components of the information processing system during the performance of a concept-mapping task. It was further proposed that through the use of scaffolding techniques during the process of concept map construction, the flow of information through the working memory system can be enhanced with the result of facilitating the concept-mapping process and enhancing conceptual knowledge development.

Chapter 3 identifies the methodology and research methods that were used to investigate the scaffolding of the concept-mapping process. The investigation of the impact of scaffolded concept mapping on the development and representation of conceptual knowledge was conducted using design-based research.
3.1 Design-based Research

The investigation of cognition in context recognises the interaction that occurs between the learner, the learning environment and the instructional activity during the learning process (Barab & Squire, 2004). Design-based research is one research methodology that has been used to examine learning in naturalistic settings by systematically adjusting different aspects of the design context (Barab & Squire, 2004) in situations where the researcher is active as an educator (Kelly, 2003). It arose from the recognition of the complexity that is associated with classroom interventions and as a result does not involve the controlling of variables or the focus on causal effects that are associated with traditional psychological experimentation, but instead attempts to find out what works in practice (O’Donnell, 2004; Shavelson et al., 2003).

At the centre of design-based research is the evolution of the designed artefact (Joseph, 2004). Design-based research is often distinguished from other research by a detailed record of the evolving design process (Shavelson et al., 2003).

In general, design-based research studies share a number of distinguishing characteristics. The first is that design studies are iterative and take place through continuous cycles of design, enactment, analysis and redesign that move toward the development of a theory that characterises the design in practice. The second is that design studies are process focussed as they seek to understand not only an individual’s reasoning and learning processes but also the impact of the design artefact on that reasoning and learning process. The third is that they often involve social interactions that include the participants as part of the design process (Barab & Squire, 2004; Design-Based Research Collective, 2003; Shavelson et al., 2003). When
conducting design-based research a number of factors that relate to the validity and reliability need to be considered.

3.1.1 Validity and Reliability of Design-based Research

One of the most important questions that must be addressed in relation to design-based research is the question of what constitutes credible evidence. While the iterative nature of design research can contribute to the production of credible evidence (O’Donnell, 2004), the issues of credibility, which is related to validity; trustworthiness, which is related to reliability; and usefulness, which is related to generalizability and external validity need to be addressed (Barab & Squire, 2004).

One of the guiding principles of scientific educational research is the need for replicability (Shavelson et al., 2003). The validation of a particular design requires not only the demonstration of the value of a particular intervention, but also the demonstration of connection to a set of theoretical constructs. Because it is difficult to replicate the findings of others, there is a need in design-based research to lay open the design and implementation process by providing rich descriptions of the context, the theoretical framework, the features of the intervention and the impact of the intervention on learning. One way that this can be done is through the use of narrative (Barab and Squire, 2004). However, Shavelson et al. (2003) caution that the validity of narrative accounts lies in the reasonableness of the explanatory framework of the argument, and that the use of narrative alone does not ensure the veracity of the content.
A second factor that is associated with design-based research is the joint role of the researcher as designer and researcher. This situation can blur the objectivity that is characteristic of experimental research as it does not allow the independence of the researcher from the learning environment, and as a result can challenge the trustworthiness of the claims that are made using design research (Barab & Squire 2004; Hoadley, 2004; O’Donnell, 2004). Barab & Squire (2004) suggest that it is the responsibility of the researcher to convince others of the trustworthiness of the claims being made and to draw on the use of techniques that are consistent with other research methodologies. O’Donnell (2004) suggests that the iterative nature of design research can contribute to the production of credible evidence. The Design-based Research Collective (2003) suggests that the methods that document processes of enactment provide essential evidence to support claims about outcomes. It is suggested that the reliability of findings can be improved through the systematic analysis of data, and through the use of standardised instruments.

A third factor is a caution about the generalizability of the findings from design-based research. Barab and Squire (2004) suggest that design-based researchers need to be clear about the limitations of their findings and that claims based on researcher-influenced contexts may not be generalised to other contexts. Difficulties with generalisation are also related to the small number of participants that are involved in the detailed analysis that is related to design-based research (O’Donnell, 2004).

Shavelson et al. (2003) support the use of design-based studies when they are appropriate to the research question. In the current study, design-based research was used to investigate the development and evaluation of scaffolded concept mapping
with a group of students who were experiencing difficulty with science learning. Design-based research was considered to be an appropriate methodology for the current study as it aimed, through the investigation of cognition in context, to impact directly on practice while at the same time advancing theory that would be of benefit to others (Barab & Squire, 2004). During the study, the scaffolding of the concept-mapping process was developed through cycles of design, implementation, analysis and redesign (Design-Based Collective, 2003). A broad outline of this process is provided below. More detailed descriptions of the context, the theoretical framework, the features of the intervention and the impact of the intervention on learning (Barab & Squire, 2004) are provided in Chapter 4, 5 and 7 of this study.

3.2 Study Method

3.2.1 Context of the Study

The current study was conducted over two school years in the School’s Learning Support Centre with a group of Year 8 and Year 9 Middle School students who had been referred to Learning Support by their class teachers because of difficulties they were experiencing with learning in their core subject areas, one of which was Science. Within the Middle School, students receive science instruction in teacher-centred mixed-ability classes of approximately 30 students. Students are involved in practical sessions for approximately 25% of their instruction time.

If students experience difficulty with learning in core subject areas such as English, Mathematics, History/Geography and Science, they study a reduced subject load and receive learning support during the times when spare study sessions have been created in their timetables. When they attend the Learning Support Centre, the students
receive assistance with their coursework individually or in small groups from a learning support teacher or a teacher aide who is working under the direction of the learning support teacher. The focus of these learning support sessions is the development of literacy and numeracy skills across the four core subject areas. These sessions are of one hour duration and generally occur four times during a two-week cycle. In the case of the current study the focus of the learning support was science coursework.

3.2.2 Study Overview

The study was conducted in three stages. In Stage 1, a student who was experiencing difficulty with science learning, identified as James was assessed, using the Working Memory Assessment Battery. The results of this assessment together with the observations made by the researcher while working with the student and the samples of work produced by the student during the tutorial sessions were used to inform the development and evaluation of the scaffolding of the concept-mapping process during Trials 1, 2, 3, and 4 of the study.

In Stage 2, a second student who was also experiencing difficulty with science learning, identified as Sam, was assessed using the Working Memory Assessment Battery. During Trials 5 and 6, the scaffolded concept-mapping process used in Trial 4 of Stage 1 of the study was re-evaluated by the researcher while working with Sam.

In Stage 3, a third student, identified as Tim, was assessed using the Working Memory Assessment Battery. During Trial 7 of the study, the scaffolded concept-mapping process developed in Trial 4 of Stage 1 of the study was implemented by a learning
support teacher aide, identified as Sue, working under the supervision of the researcher, with Tim. In Trial 8 of the study this concept-mapping process was then re-evaluated with an additional group of four teacher aides (Mary, Jan, Helen, Lyn) who worked under the supervision of the researcher with students who had been referred to Learning Support.

Table 3.1

Summary of the Stages of the Study

<table>
<thead>
<tr>
<th>Stage</th>
<th>Trial Number</th>
<th>Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage 1</td>
<td>Trial 1</td>
<td>James, researcher</td>
</tr>
<tr>
<td>Stage 1</td>
<td>Trial 2</td>
<td>James, researcher</td>
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<tr>
<td>Stage 1</td>
<td>Trial 3</td>
<td>James, researcher</td>
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<tr>
<td>Stage 1</td>
<td>Trial 4</td>
<td>James, researcher</td>
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<tr>
<td>Stage 2</td>
<td>Trial 5</td>
<td>Sam, researcher</td>
</tr>
<tr>
<td>Stage 2</td>
<td>Trial 6</td>
<td>Sam, researcher</td>
</tr>
<tr>
<td>Stage 3</td>
<td>Trial 7</td>
<td>Tim, researcher, teacher aide (Sue)</td>
</tr>
<tr>
<td>Stage 3</td>
<td>Trial 8</td>
<td>Learning Support students, researcher, teacher aides (Mary, Jan, Helen, Lyn)</td>
</tr>
</tbody>
</table>

3.2.3 Study Participants

3.2.3.1 The researcher

In the current study the researcher had the dual role of researcher and designer. My direct involvement in science teaching began in the 1970s and continued until the early 1990s. During that time I was involved in the development, teaching and evaluation of general science courses in Years 8 to 10 and Biological Science, Chemistry and Multi-Strand Science in Years 11 and 12. Since that time my teaching has been in the area of Learning Support. In my current role as Head of Learning
Support I am involved with the support of students’ learning within the School from Preparatory Year to Year 12.

3.2.3.2 The students – Trials 1-7 (James, Sam and Tim)

In the current study three students James, Sam and Tim participated in Trials 1-7 of the scaffolded concept-mapping process. These students were also assessed using the Working Memory Assessment Battery. Each of these students had been attending the Learning Support Centre for differing periods of time. When students commence their attendance at Learning Support a meeting is held with parents and signed permission for attendance is obtained. In the case of the current study, additional informed-consent was obtained from both parents and students. Contact details were provided for the researcher and for the Research Ethics Officer. Information letters outlined the perceived benefits of the study for the development of the school curriculum and the manner in which data would be collected.

At the time of selection for the study each of the students was achieving at a “Consolidating” grade level on their science class tests. These class tests assessed conceptual knowledge in science using a combination of multiple choice and short answer questions. The “Consolidating” grade level meant that students had not yet grasped a clear understanding of science concepts. All of the students were experiencing a particular difficulty with representation of conceptual understanding in written form on the “short answer” component of the science tests.
In addition, over the period of time that the students had attended Learning Support background assessment information had been collected for each of these students from a number of sources. These included:

1. *The Queensland Year 7 Tests in Aspects of Literacy and Numeracy* (Queensland Studies Authority, 2005). The literacy tests contain questions from the areas of reading and viewing, spelling, and writing. The numeracy tests contain questions from the areas of number, measurement and data and space. Students would be considered to be at risk if their performance falls below that of the middle 50% of students.

2. *The Progressive Achievement Tests in Reading Comprehension* (PAT-R) (Australian Council for Educational Research, 2001). These tests are designed to assist teachers in their assessment of reading comprehension skills. The tests consist of four reading test forms. Each of these tests contains eight or nine passages accompanied by comprehension questions that are presented in a multiple choice format. All of the questions are intended to measure literal and inferential comprehension. Test performance below a Percentile Rank of 22 is considered to be in the “below average range”.

3. *The Progressive Achievement Tests in Mathematics* (PAT Maths) (Australian Council for Educational Research, 1998). These tests are designed to provide teachers with information about the level of student achievement in the skills and understandings of mathematics. The test items are arranged in content groups in the areas of number, space, measurement and data, and algebra. Test performance below a Percentile Rank of 22 is considered to be in the “below average range”.

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4. *The Tests of Reading Comprehension* (TORCH) (Mossenson, Hill, & Masters, 1987) are a set of 14 un-timed reading tests that aim to assess the extent to which readers are able to obtain meaning from text. Test performance below Percentile Rank 24 is considered to be in the “below average range”.

5. *Woodcock-Johnson 111 Diagnostic Reading Battery* (WJ 111 DRB) – Letter-Word Identification subtest (Woodcock, Mather, & Schrank, 2004). This subtest measures the subject’s word identification skills. The Standard Score scale of the WJ 111 DRB is based on a mean of 100 and a standard deviation of 1.

A summary of background information for each of these students is now provided.

### 3.2.3.3 James’s Background Information

*James* entered the School at the beginning of Year 7. During that year he was referred to Learning Support because of the difficulty that he was experiencing with his core subjects one of which was science. When James completed the Queensland Year 7 Test in Aspects of Literacy and Numeracy he scored below the middle 50% of students in the areas of Reading and Viewing, Spelling and Writing. He scored within the middle 50% of students in the areas of Numeracy, Number, Measurement and Data and Space. In the Screening assessments that were conducted by the Learning Support Department, James scored at a Percentile Rank of 8 on the TORCH comprehension test, at a Percentile Rank of 67 on the PAT Maths 3B Test and at a Percentile Rank of 33 and Standard Score of 94 on the Letter Word Identification subtest of the Woodcock-Johnson 111 Diagnostic Reading Battery. Trials 1, 2 and 3 of the current study were conducted with James while he was in Year 8. At that time he was 13 years. Trial 4 of the study was conducted when James was in Year 9.
3.2.3.4 Sam’s Background Information

Sam was referred to Learning Support because of the difficulties that he was experiencing with his coursework in Year 6. When Sam completed the Queensland Test Year 7 Test in Aspects of Literacy and Numeracy, he scored below the middle 50% of students in the areas of Reading and Viewing, Numeracy and Number. He scored within the middle 50% of students for Spelling, Writing and Measurement and Data and Space. In the Screening assessments that were conducted by the Learning Support Department, Sam scored at a Percentile Rank of 9 on the PAT R Comprehension Test, at a Percentile Rank of 25 on the PAT Maths 3R Test and at a Percentile Rank of 54 and a Standard Score of 101 on the Letter-Word Identification subtest of the Woodcock-Johnson Diagnostic Reading Battery. Trials 5 and 6, of the study were conducted when Sam was in Year 8. At that time he was 13 years.

3.2.3.5 Tim’s Background Information

Tim entered the School at the beginning of Year 7. He was referred to Learning Support because of the difficulty that he was experiencing with his core subjects one of which was Science. When Tim completed the Queensland Year 7 in Aspects of Literacy and Numeracy he scored below the middle 50% of students in the areas of Reading and Viewing, Numeracy, Number and Measurement and Data. He scored within the middle 50% of students in the areas of Spelling, Writing, and Space. In the Screening assessments that were conducted by the Learning Support Department, Tim scored at a Percentile Rank of 6 on the PAT R Comprehension Test, at a Percentile Rank of 17 on the PAT Maths 3R Test and at a Percentile Rank of 27 and a Standard Score of 91 on the Letter-Word Identification sub-test of the Woodcock-Johnson 111
Diagnostic Reading Battery. Trial 7 of the study was conducted when Tim was in Year 8. At that time he was 13 years.

3.2.3.6 The teacher aides

The teacher aides who worked with the students to implement the scaffolded concept-mapping process in Trials 7 and 8 of the study were a mature group of women who had worked as teacher aides for a period of at least 4 years. All of the teacher aides were completing or had completed an external teacher aide training course at a certificate level or higher. Each of the teacher aides was familiar with working with Middle School students in their mainstream classrooms, in subjects such as English and Mathematics. In addition, they worked with students in the Learning Support Centre. In Trial 7 of the study the teacher aide who worked with Tim is referred to as Sue. In Trial 8 of the study the teacher aides who worked with the additional group of learning support students are referred to as Mary, Jan, Lyn and Helen.

3.2.3.7 The additional learning support students who worked with the teacher aides

The additional learning support students who worked with the teacher aides in Trial 8 of the study were a group of eight Year 9 students who had been referred to Learning Support because of the difficulties they were experiencing with reading comprehension in their coursework subjects including Science. This group consisted of 2 female and 6 male students. Students were nominated for this group if they had below average performance on The Progressive Achievement Tests in Reading Comprehension (PAT-R) (Australian Council of Educational Research, 2001).
3.2.4 Sources of science text

The chapters of science text that were used in the current study were sourced from Science World 8 (Stannard & Williamson, 2000) and Science World 9 (Stannard & Williamson, 2000). These were the students’ prescribed science texts.

3.2.5 Working Memory Assessment

The model of working memory that was developed in Chapter 2 assumed that short-term memory, long-term memory and working memory are interrelated aspects of the one memory system (Baddeley et al., 1988; Swanson, 1986; Swanson & Sachse-Lee, 2001a). It also was assumed that working memory consists of domain-specific and domain-general storage and processing components, each of which has an individual functioning capacity (Baddeley, 2002). One of the difficulties associated with the assessment of working memory is in confirming which aspects of the functioning of the working memory system each test is actually measuring (Pickering, 2006).

One assessment tool that has been widely used to investigate individual differences in working memory capacity is the Test of Working Memory Span. In this test subjects are required to read aloud a series of sentences and then recall the final word of each sentence. The working memory span is represented by the total number of the final words from each sentence that is recalled (Daneman & Carpenter, 1980). While there has been a considerable amount of experimental work done on working memory span tasks there is little evidence to confirm that these measures have either conceptual or construct validity. Even if it is established that they measure a common construct it has not been confirmed whether working memory tasks measure processes that are different from those measured by short-term memory tasks (Engle, Laughlin,
Tuholski, & Conway, 1999). Engle et al. investigated this question by measuring the unique and shared variance across short-term memory and working span tasks to determine whether two separate constructs of short-term memory and working memory can be identified. The results of the study indicated that short-term memory and working memory are two distinguishable but highly related constructs. These findings are also supported by the research of Bayliss et al. (1999) and Swanson (1994).

Research conducted by Kane et al. (2004) indicates that working memory span tasks involve the joint contributions of the domain-general executive and domain-specific rehearsal, coding and storage components of the working memory system. The authors used a latent variable study to investigate whether measures of verbal and visuo-spatial working memory capacity represent the functioning of a primarily domain-general construct. The results of factor analyses and structural equation models confirmed that working memory span tasks largely reflected a domain-general factor while short-term memory tasks based on the same stimuli as the working memory tasks were more domain-specific. The results support the domain-general view of working memory capacity in which executive attentional processes are related to performance on working memory span measures, while domain-specific storage and rehearsal are related more to the domain-specific aspects of complex cognition.

Research conducted by Bayliss et al. (2003), Engle et al. (1999) and Swanson (1994) has identified separate domain-specific and domain-general components of the working memory system. Kane et al. (2004) indicate that working memory span tasks largely reflect the capacity of a domain-general factor while short-term memory tasks
based on the same stimuli as working memory span tasks are more domain-specific, while Engle et al. (1999) caution that this dichotomous view of short-term and working memory may prove to be too simplistic. Baddeley (2002) suggests that the total capacity of the working memory system is reflected in the working memory span.

A second assessment instrument of working memory that has been designed using the tripartite model of working memory proposed by Baddeley (1981) is the *Working Memory Test Battery for Children* (Pickering, 2006). This assessment instrument aims to measure the functioning of the phonological loop, visuo-spatial sketchpad and central executive components of the working memory system. It does not include a measure of the episodic buffer component of working memory as the measurement of the functioning of this component of the working memory system has not been widely investigated (Pickering, 2006). The test uses a series of subtests such as digit recall, word-list recall, mazes memory and visual patterns to measure the functioning of the phonological loop and visuo-spatial sketchpad components of working memory. The functioning of the central executive is measured using listening and counting recall subtests related to the complex span task developed by Daneman and Carpenter (1980). These tests require both the storage and processing of information.

Additional examples of tasks that have been used to measure verbal short-term memory include forward digit recall, word and non-word recall (Kane et al., 2004; Gathercole & Pickering, 2000; Woody-Dorning & Miller, 2001). Tasks used to measure visuo-spatial short-term memory include object location (Woody-Dorning & Miller, 2001) and measures of visual patterns such as arrow span and ball span (Kane
et al., 2004). A large number of the tasks that have been used to measure working memory span are modified versions of the reading span task developed by Daneman and Carpenter (Gathercole & Pickering, 2000; Hooper et al., 2002; Swanson, 1995; Wilson & Swanson, 2001). In addition, some of the studies that have investigated working memory capacity have selected measures of working memory that resemble the requirements of the task under investigation (Woody-Dorning & Miller, 2001). Others have taken into consideration the nature of the stimuli presented in both the short-term memory and working memory span tasks (Kane et al., 2004). These factors were taken into consideration in the selection of assessment instruments for this study.

In the current study, the measurement of the functioning of components of working memory will be based on the three component model of working memory described by Baddeley (1981). It will be assumed that while measures of working memory span will be considered to reflect mainly the capacity of the domain-general subcomponent of working memory, limitations in the functioning of the domain-specific verbal and visuo-spatial subcomponents of working memory will impact on measures of the domain-general central executive (Baddeley, 2002; Engle et al., 1999).

As part of Stages 1, 2 and 3 of the study three students (i.e., James, Sam and Tim) were assessed using a Working Memory Assessment Battery that was assembled using subtests from the Test of Memory and Learning (Reynolds & Bigler, 1994), the Test of Auditory-Perceptual Skills: Upper Level (Gardner, 1994) and the Swanson Cognitive Processing Test (Swanson, 1996). The assessment tasks were used to measure the functioning of the phonological loop, visuo-spatial sketchpad and central executive components of working memory. The assessments took place over two
sessions of approximately one hour when the students were attending their regular learning support sessions.

The assessment tasks used to measure the capacity of the domain-specific phonological loop were:

1. A subtest of *The Test of Memory and Learning* (Reynolds & Bigler, 1994): *Digits Forward*, which is a standard verbal number recall task that measures the rote recall of a series of numbers. Digit recall test have been said to provide a measure of the capacity of the phonological store with contributions from long-term memory and in older children from rehearsal processes (Pickering, 2006).

2. A subtest of *Test of Auditory-Perceptual Skills: Upper Level* (Gardner, 1994): *Auditory Word Memory*, which is a test that requires the students to recall a series of single words of increasing length, that is not meaningful. Word recall tests have been said to provide a measure of the capacity of the phonological store component of working memory with contributions from semantic and visual long-term memory, from visual working memory and from active rehearsal processes (Pickering, 2006).

The assessment tasks that were used to measure the capacity of the domain-specific visuo-spatial sketchpad were subtests of *The Test of Memory and Learning* (Reynolds & Bigler, 1994) including:
1. *Abstract Visual Memory*, which is a nonverbal test that measures students’ immediate recall of meaningless figures when order is not important. Visual pattern tests provide a measure of the visual subcomponent of visuo-spatial working memory (Pickering, 2006).

2. *Visual Sequential Memory*, which is a nonverbal task that requires the student to recall the sequence of a series of meaningless geometric designs (Reynolds & Bigler, 1994).

3. *Memory for Location*, which is a nonverbal task that measures spatial memory (Reynolds & Bigler, 1994).

The working memory span tasks were used to measure the capacity of the domain-general central executive. These were subtests of *The Swanson Cognitive Processing Test* (Swanson, 1996) including:

1. *Semantic Categorization*. The subtest assesses the student’s ability to recall word associations within categories.

2. *Visual Matrix*. The subtest assesses the student’s ability to recall the position of dots in a matrix that follows a sequential pattern.

A summary of the assessment instruments used to assess the functioning of the phonological loop, visuo-spatial sketch pad and central executive subcomponents of working memory is shown in Table 3.2.
### Table 3.2

**Summary of Tests Used to Assess Each Subcomponent of the Working Memory System**

<table>
<thead>
<tr>
<th>Area of Model</th>
<th>Type of Working Memory Processing</th>
<th>Name of Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phonological Loop</td>
<td>Domain-specific</td>
<td>Test of Memory and Learning a) Digits Forwards</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Test of Auditory Perceptual Skills a) Auditory Word Memory</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Test of Memory and Learning a) Abstract Visual Memory</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) Visual Sequential Memory c) Memory for Location</td>
</tr>
<tr>
<td>Visuo-spatial Sketchpad</td>
<td>Domain-specific</td>
<td>Swanson Cognitive Processing Test a) Semantic Categorization</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) Visual Matrix</td>
</tr>
<tr>
<td>Central Executive</td>
<td>Domain-general</td>
<td>Swanson Cognitive Processing Test a) Semantic Categorization</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) Visual Matrix</td>
</tr>
</tbody>
</table>

3.2.5.1 *Validity and reliability of working memory assessment instruments.*

The tests that were used to measure the capacity of the domain-specific phonological loop subcomponent of working memory have been selected from the *Test of Memory and Learning* (Reynolds & Bigler, 1994) and from the *Test of Auditory-Perceptual Skills: Upper Level* (Gardner, 1994). These assessment instruments were chosen, as they require the student to remember small amounts of verbal information that are held passively and then recalled in a sequential and unchanged form (Swanson, 1995). These tests are in keeping with similar assessment instruments such as digit, word and non-word recall that have been used in previous studies to measure the capacity of the domain-specific verbal subcomponent of working memory (Gathercole & Pickering, 2000; Kane et al., 2004; Woody-Dorning & Miller, 2001). The Cronbach alpha procedure was used to determine reliability. The alpha coefficient reliability (r) for each of the subtests to be used in this study is given as Digits Forward \( r = 0.96 \),
Letters Forward $r = 0.97$ at age 14 (Reynolds & Bigler, 1994) and Auditory Word Memory $r = 0.71$ (Gardner, 1994).

The tests that were used to measure the domain-specific visuo-spatial subcomponent of working memory were selected from the Test of Memory and Learning (Reynolds & Bigler, 1994). These assessment instruments were chosen, as they require the student to store and remember small amounts of visuo-spatial information in a sequential and unchanged form (Swanson, 1995). These tests are in keeping with similar assessment instruments such as object location and visual patterns that have been used in previous studies to measure the capacity of the domain-specific visuo-spatial subcomponent of working memory (Kane et al., 2004, Woody-Dorning & Miller, 2001). The alpha coefficient reliability ($r$) for each of the subtests to be used in this study is given as Abstract Visual Memory $r = 0.90$, Visual Sequential memory $r = 0.95$ and Memory for Location $r = 0.98$ (Reynolds & Bigler, 1994).

The test that was used to measure the domain-general central executive subcomponent of working memory is the Swanson Cognitive Processing Test (S-CPT), (Swanson, 1996). This assessment instrument was selected as all of the working memory subtests have been designed so that they require the simultaneous processing and storage of information and are in keeping with similar assessment instruments used to measure the domain-general central executive subcomponent of working memory (Kane et al., 2004; Swanson, 1996). The construct validity of the S-CPT was established by correlating the various subtests with a common experimental measure of working memory, the Sentence Span Task (Swanson, 1996). A correlation coefficient provides a measure of the relationship between two variables. When $r = 1$,
one variable is predicted perfectly from the other. The Pearson Product-Moment Correlations between the scores on the S-CPT subtests and the Sentence Span Task ranged between 0.39 and 0.65. All were considered to be significant and supported the notion that the various subtests are related to working memory. The alpha coefficient reliability (r) for the subtests selected for the study ranged between 0.72 and 0.81 (Swanson, 1996).

At the completion of Trial 6 a number of additional assessments were administered. These assessments were used to investigate the language processing of James and Sam. At this time the following tests were administered.

1. *The Peabody Picture Vocabulary Test Third Edition* (PPVT 111) (Dunn & Dunn, 1997). The PPVT 111 is a test of listening comprehension of the spoken word in standard English. It is designed to measure a person’s level of vocabulary acquisition.

2. *The Clinical Evaluation of Language Fundamentals Screening Test – Fourth Edition* (CELFST-4) (Semel, Wiig, & Second, 2004). The CELFST-4 is a test designed to screen students for language disorders. Subtests include measures of word structure, concepts and following directions, recalling sentences, sentence assembly, semantic relationships and word classes.
3.2.6 The Development, Trialling and Evaluation of the Scaffolded Concept-Mapping Process

The scaffolded concept-mapping process was developed and evaluated using a series of eight trials. Trial 1, 2, 3, and 4 were conducted by the researcher while working with James. Trials 5 and 6 were conducted while the researcher was working with Sam. Trial 7 was conducted under the supervision of the researcher by a teacher aide who was working with Tim. In Trial 8, the scaffolded concept-mapping process was implemented by teacher aides who were working under the supervision of the researcher. During these trials a number of scaffolding techniques were evaluated.

The literature review outlined in Chapter 2 identified working memory as the site for new knowledge construction (Baddeley, 2002; Novak & Canas, 2006) and the essential role of the complex interaction between the knowledge, memory and strategy components of the information processing system during the process of conceptual knowledge development (Kolligan & Sternberg, 1987; Swanson 1988). Specific factors that have been linked to the effective utilisation of a strategy such as concept mapping include working memory capacity (Imbo & Vandierendonck, 2007; Keeler & Swanson, 2001) and knowledge availability including domain-specific (Afflerbach 1990) and metacognitive knowledge (Borkowski et al., 1987; Conner; 2007). In Chapter 2 specific scaffolding techniques that have the potential to influence the exchange of information in working memory during the performance of a concept-mapping task were identified. These include the explicit teaching of concepts (Cambourne, 1999; Hudson et al., 2006), graphic organisers (Marcus et al., 1996; Gerlic & Jausovec, 1999), interactive dialogue (Duffy & Roehler, 1987; Palincsar, 1986; Scott, 1998) and writing (Gunel et al., 2007; Hand et al., 2007). Essentially, the
aim of using these scaffolding techniques was to maximise the depth of processing of conceptual information in working memory while at the same time controlling the high cognitive load associated with the concept-mapping task.

In the current study combinations of the following scaffolding techniques were used.

1. *Key concept lists.* Novak and Canas (2006) suggest the use of a list of key concepts as a starting point for the construction of a concept map. In the current study each of the lists of key concepts was prepared by the researcher and represented the key ideas contained in each chapter of the science text. In the current study, these key concept lists were used to assist the students with the location of the key conceptual information in the texts.

2. *Written Concept statements.* Writing has been used in science classrooms as a means of actively engaging students in the process of knowledge construction (Baker et al., 2008) and enabling students to review visually newly learned information (Meiers & Knight, 2007). In particular vocabulary definitions have been used to improve vocabulary knowledge and reading comprehension (Viadero, 2006; Yeung, 1999). In the current study, student-constructed vocabulary definitions were used to assist students’ learning of the key concept-related information contained in the text.
3. **Concept cards to be used during concept map construction.** This form of scaffolding has been used to provide students with a means of physically manipulating the concepts while they were thinking about the position of the concepts on the concept map. (Novak et al., 1983; White & Gunstone, 1992). In the current study, concept cards were used to aid the process of concept map construction by assisting with the flexible, visual placement of concepts.

4. **Responsive elaboration.** Responsive elaboration is an instructional technique that has been used to facilitate students’ understanding of the use of reading strategies. It requires the teacher firstly to use students’ responses to identify areas of misunderstanding and then to use cycles of additional explanation to facilitate the development of students’ understanding (Roehler & Duffy, 1987). In the current study this technique was used to facilitate the development of students’ conceptual knowledge during the development of written concept statements and with the development of conceptual understanding during the process of concept map construction.

5. **Mental modelling.** Mental model has been described as a teaching technique that informs students about the flexible reasoning processes that underlie strategic reading (Duffy et al., 1988). In the current study mental modelling was used to provide students with feedback about the use of the concept mapping strategy aimed at developing students’ metacognitive knowledge about strategy use.
6. *Spoke word maps.* It has been suggested that by representing interacting knowledge elements in a diagrammatic schema there will be a reduction in cognitive load during the processing of that information and as a result understanding will be enhanced (Marcus et al., 1996; Robinson et al., 1998). Kinchin et al. (2000) suggest that spoke word maps may represent an initial level of students’ conceptual development. Young (2005) used spoke word maps, referred to as definition maps, to aid the development of vocabulary understanding in science. In the current study, student-constructed spoke word maps were developed using Inspiration 6 (Helfgott & Westhaver, 1998) and were used to provide students with a visual representation of the textural information that was related to each of the key concepts on the concept lists. Inspiration 6 provides students with a software tool that can be used to develop the linkages between concepts in the form of various types of visual diagrams.

7. *Spoke concept maps.* A study conducted by Bos and Anders (1990) identified the positive impact of semantic mapping and semantic feature analysis techniques that emphasised the relationships between concepts on the development of vocabulary knowledge and understanding in science. It was suggested that the semantic analysis of vocabulary terms encouraged students to think about what they already knew about the concepts and how the concepts might be related to one another. In the current study, spoke concept maps were used to provide students with a way of meaningfully linking the key conceptual information for each of the key
concepts in a visual form. The spoke concept maps were constructed using Inspiration 6 (Helfgott & Westhaver, 1998).

8. Partially-completed concept maps. Partially-completed concept maps have been used to provide a partial solution to the problem of concept map construction with the aim of reducing the cognitive load associated with the concept-mapping process (Chang et al., 2001, 2002; Sweller et al., 1998). In the current study, the partially-completed concept maps were developed using the completed whole-chapter concept maps that had been prepared by the researcher from the information contained in the textbook. The maps were constructed using Inspiration 6 (Helfgott & Westhaver, 1998). The textbook was used as the source of conceptual information as the aim of the study required students to construct a concept map using their science text. Each of the partially-completed maps for a chapter formed a part of the researcher-constructed whole-chapter concept map. On these partially-constructed maps the positioning of the concepts was retained and the conceptual links removed. In the current study, the partially-completed concept maps were used to provide the students with a visual representation of related concepts and to reduce the cognitive load associated with the process of meaningful link construction.

9. Extended recall conceptual questions. Writing-to-learn has been used in science classrooms as a means of developing conceptual understanding by enabling the learner to refine and elaborate new knowledge (Baker et al., 2008; Gunel, Hand, & Prain, 2007; Van Boxtel et al., 2002). In the current
study, writing was used to provide students with a means of elaborating
their conceptual knowledge and as a means of tracking students’
conceptual development.

Specific details of the use of these scaffolding techniques are provided in Chapter 4
and 5. A summary of the text chapters and scaffolding activities used in each trial is
given in Table 3.3.
Table 3.3

*Text Chapters and Scaffolding Activities Used in Each Trial*

<table>
<thead>
<tr>
<th>Trial</th>
<th>Student</th>
<th>Text Chapter</th>
<th>Scaffolding Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>James</td>
<td>Science World 8 – Electricity</td>
<td>Concept list, Written concept statements, Responsive elaboration</td>
</tr>
<tr>
<td>2</td>
<td>James</td>
<td>Science World 8 – Food for life</td>
<td>Concept list, Written concept statements, Concept cards, Responsive elaboration</td>
</tr>
<tr>
<td>3</td>
<td>James</td>
<td>Science World 8 – Building blocks of Life</td>
<td>Concept list in subsets, Spoke word map, Written concept statements, Responsive Elaboration</td>
</tr>
<tr>
<td>4</td>
<td>James</td>
<td>Science World 9 – Living with acids and bases</td>
<td>Concept list in subsets, Spoke word map, Spoke concept map, Written concept statements, Responsive Elaboration, Mental Modelling, Partially-completed concept map, Extended recall conceptual questions</td>
</tr>
<tr>
<td>5</td>
<td>Sam</td>
<td>Science World 8 – The living world</td>
<td>Concept list in subsets, Spoke word map, Spoke concept map, Mental Modelling, Responsive Elaboration, Partially complete concept map, Extended recall conceptual questions</td>
</tr>
<tr>
<td>6</td>
<td>Sam</td>
<td>Science World 8 – What are things made of?</td>
<td>As in Trial 4</td>
</tr>
<tr>
<td>7</td>
<td>Tim</td>
<td>Science World 8 – What are things made of?</td>
<td>As in Trial 4</td>
</tr>
<tr>
<td>8</td>
<td>Year 9 learning support students</td>
<td>Science World 9 – Living with acids and bases</td>
<td>As in Trial 4</td>
</tr>
</tbody>
</table>

The scaffolded concept-mapping process was implemented with teacher aide assistance in Stage 3 of the study during Trials 7 and 8. At the end of Trial 7, a
number of teacher aide supports were developed to facilitate the implementation of the scaffolded concept-mapping process. These included:

1. A Science Curriculum Booklet that included sample student responses and instructions for the delivery of the scaffolded concept-mapping process. Details of these booklets are provided in Chapter 7.
2. A Teacher Aide Checklist. Details of this checklist are given in Chapter 7.
3. Teacher aide training sessions. An outline of the topics covered in these training sessions is given in Chapter 7.
4. Teacher aide survey questions. These questions are outlined in Chapter 7.

3.3 Data Analysis

The data collected during the study included students’ working memory profiles, student-constructed concept maps and writing samples and observations made by the researcher while working with the students and the teacher aides.

3.3.1 Analysis of Individual Differences in Students’ Working Memory Profiles

The results obtained from the assessment of working memory provided information regarding individual differences in the functioning of the phonological loop, the visuo-spatial sketchpad and the central executive components of working memory. The scores for each subtest were converted to standard scores using the established norms for each subtest. Students were considered to have experienced significant difficulty with a particular subtest if their subtest score fell more than one standard deviation below the mean for students of the same age. Students were considered to have below average functioning in a particular subcomponent of working memory if
the majority of the subtest scores for that subcomponent fell more than one standard deviation below the mean.

Possible patterns of working memory functioning included:

1. Below average phonological loop functioning, average visuo-spatial capacity, average central executive functioning.
2. Below average phonological loop functioning, average visuo-spatial capacity, below average central executive functioning.
3. Average phonological loop functioning, below average visuo-spatial capacity, average central executive functioning.
4. Average phonological loop functioning, below average visuo-spatial capacity, below average central executive functioning.
5. Below average phonological loop functioning, below average visuo-spatial capacity, below average central executive functioning.

3.3.2 Analysis of the Development and Representation of Conceptual Knowledge

The development and representation of conceptual understanding during the trialling of the scaffolded concept-mapping process was evaluated in two ways. These were concept map analysis and the analysis of writing samples.

3.3.2.1 Analysis of concept maps

In the current study, in order to investigate individual differences in the structure and content of concept maps, qualitative methods of concept map analysis were used. Broadly the analysis of the maps related to the overall map structure, the way in
which the concepts were linked and the clarity of the propositions represented on the map (Hay, 2007, Kinchin et al., 2000).

The study conducted by Kinchin et al., (2000) identified three main types of concept map structure. These are a spoke, which is a radial structure in which all of the related concepts are directly linked only to the core concept, a chain, which is a linear structure in which individual concepts are only linked to the ones immediately above and below and a net, which is a highly interrelated and hierarchical network that represents a deep understanding of the topic. It is suggested that these structures represent different levels of understanding of the topic. Maps are analysed on the basis of a number of criteria. Firstly, map complexity that ranges from little integration for the spoke structure to a high level of integration for the net structure. Secondly, relationship to the expert view that ranges from simple associations that demonstrate no understanding of interaction on the spoke; for example, “flowers have female parts”, to complex interactions that identify relationships at a more complex conceptual level on the net for example “insects feed on nectar”. Thirdly, map hierarchy that ranges from one level for the spoke to several levels for the net.

The method of map analysis developed by Kinchin et al., (2000) avoids the process of assessing link validity and recognises invalid links to be as important as valid links. It is suggested that invalid links reveal much about the student’s thought processes and can be used by the teacher as diagnostic data to provide assistance to the student. The importance of conceptual links as a representation of students’ understanding is supported by Fensham et al. (1982), Novak and Canas (2006), Rye and Ruba (2002) and Williams (1998). A recent study conducted by Hay (2007) provides a means of
concept map analysis that reflects the changes that occur in students’ knowledge structures during learning. In this study, three descriptions of conceptual change are identified. These include deep learning, surface learning and non-learning. Deep learning is characterised by a progression in concept analysis that reflects an overall improvement in the organisation, linkage and clarity of propositions from one map to the next. Surface learning is characterised by an increase in the number of new concepts, but these concept are not integrated in a meaningful way on the map. Non-learning is characterised by the absence of meaningful linkages from one map to the next. In this study, students’ individual concept maps are presented and analysed to provide evidence of the changes that occurred in students’ knowledge structures.

In the current study, concept maps were analysed with reference to the overall map structure, the way in which the concepts were linked and the clarity of the propositions represented on the map.

3.3.2.2 Analysis of writing samples

Writing samples were analysed using the underlying components of language described by Brice (2004). Five components of language that are linked to specific writing skills are identified. The first is phonology; that is the study of the speech sound system and is reflected in writing skills such as spelling. The second is morphology; that is the study of word structure and is reflected in writing skills such as spelling, syllabification and past tense. The third is semantics that includes vocabulary, word meanings and the relationship between different words and is reflected in vocabulary and word relationships. The fourth is syntax; that is the rule system that determines how words are combined into meaningful units in sentences.
and is reflected in grammar, sentence structure, capitalisation and punctuation. The fifth is pragmatics that relates to the ability to initiate and maintain cohesive information and is reflected in cohesion and conciseness of thought in a written sentence.

These five components of language were used to analyse the writing samples produced by James and Sam during Trials 1 to 6 of the study. This analysis is contained in Chapters 4 and 5.

3.3.3 Observations made by the researcher

Observations were recorded by the researcher during and on the completion of each session. These observations are outlined in Chapters 4, 5 and 7.

3.3.4 Analysis of Scaffolded Concept Mapping Using Teacher Aide Assistance

The implementation of the scaffolded concept-mapping process using teacher aide assistance was evaluated using:

1. The observations made by the researcher while working with the teacher aides during Trials 7 and 8.
2. The evaluation of the Teacher Aide Checklist that was used by the teacher aides to record observations while working with the students in Trial 8 during the use of the scaffolded concept-mapping process. Details of this checklist can be found in Chapter 7.
3. The evaluation of the teacher aide survey questions that were completed by the teacher aids after they had worked with the students in Trial 8 using
the scaffolded concept-mapping process. Details of these survey questions can be found in Chapter 7.

A summary of the participants, assessment instruments, scaffolding activities and evaluation methods used in each trial of study are provided in Table 3.4.
<table>
<thead>
<tr>
<th>Trial/Participant</th>
<th>Assessment Instrument</th>
<th>Scaffolding Activities</th>
<th>Evaluation Methods</th>
</tr>
</thead>
</table>
| 1. James, researcher        | Working Memory Assessment Battery | Concept list  
Written concept statements  
Responsive elaboration | Analysis of working memory profile  
Analysis of concept maps  
Analysis of writing samples  
Researcher Observations |
| 2. James, researcher        |                                  | Concept list  
Written concept statements  
Concept cards  
Responsive elaboration | Analysis of concept maps  
Analysis of writing samples  
Researcher observation |
| 3. James, researcher        |                                  | Concept list in subsets  
Spoke word maps  
Written concept statements  
Responsive elaboration | Analysis of concept maps  
Analysis of writing samples  
Researcher observation |
| 4. James, researcher        |                                  | Concept list in subsets  
Spoke Word Maps  
Spoke concept maps  
Written concept statements  
Responsive elaboration  
Mental modelling  
Partially-complete concept map  
Extended recall conceptual questions | Analysis of concept maps  
Analysis of writing samples  
Researcher observation |
| 5. Sam, researcher          | Working Memory Assessment Battery | Concept list in subsets  
Spoke Word Maps  
Spoke concept maps  
Responsive elaboration  
Mental modelling  
Partially-complete concept map  
Extended recall conceptual Questions | Analysis of working memory profile  
Analysis of concept maps  
Analysis of writing samples  
Researcher observations |
| 6. Sam, researcher          |                                  | Scaffolding sequence as in Trial 4 | Analysis of working memory profile  
Analysis of concept maps  
Analysis of writing samples  
Researcher observations |
| 7. Tim, researcher          | Working Memory Assessment Battery | Scaffolding sequence as in Trial 4 | Analysis of working memory profile  
Analysis of concept maps  
Analysis of writing samples  
Researcher observations |
| 8. Year 9 learning support students, researcher, teacher aides (Mary, Jan, Helen, Lyn) | Scaffolding sequence as in Trial 4 | Analysis of concept maps  
Analysis of writing samples  
Researcher observations  
Teacher aide checklist  
Teacher aide survey questions |
Stage 1: The Development of the Scaffolded Concept-Mapping Process

In Stage 1 of the study, a student identified as James, who was experiencing difficulty with science learning, was assessed using the *Working Memory Assessment Battery*. The results of this assessment together with the observations made by the researcher while working with James were used to inform the development and evaluation of the first four trials of the scaffolded concept-mapping process. Stage 1 of the study was conducted within the framework of a design-based research methodology through the use of a cyclic process of design, implementation, evaluation and redesign (Barab & Squire, 2004). Stage 1 of the investigation is discussed in Chapter 4. The inferences drawn in the evaluation of each trial of the scaffolded concept-mapping process represent the researcher’s interpretation of the student’s assessment profile, the verbal interactions that occurred between James and the researcher and of the samples of work that he produced during the tutorial sessions.

4.1 James’s Working Memory Profile

4.1.1 James’s Working Memory Assessment Summary

James was assessed using the *Working Memory Assessment Battery* that measured the functioning of the phonological loop, visuo-spatial sketchpad and central executive components of his working memory system. A summary of the test scores obtained from the assessment of working memory is shown in Table 4.1.
Table 4.1

**Summary of James’s Working Memory Assessment**

<table>
<thead>
<tr>
<th>Component of Working Memory</th>
<th>Name of Test</th>
<th>Level of Functioning Scaled Score</th>
<th>Level of Functioning Descriptor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phonological Loop</td>
<td>Digits Forward</td>
<td>6</td>
<td>Below Average</td>
</tr>
<tr>
<td>Phonological Loop</td>
<td>Auditory Word Memory</td>
<td>8</td>
<td>Low Average</td>
</tr>
<tr>
<td>Visuo-spatial Sketchpad</td>
<td>Visual Sequential Memory</td>
<td>11</td>
<td>Average</td>
</tr>
<tr>
<td>Visuo-spatial Sketchpad</td>
<td>Abstract Visual Memory</td>
<td>13</td>
<td>High Average</td>
</tr>
<tr>
<td>Visuo-spatial Sketchpad</td>
<td>Memory for Location</td>
<td>14</td>
<td>Above Average</td>
</tr>
<tr>
<td>Central Executive</td>
<td>Semantic Organisation</td>
<td>9</td>
<td>Average</td>
</tr>
<tr>
<td>Central Executive</td>
<td>Visual Matrix</td>
<td>12</td>
<td>High Average</td>
</tr>
</tbody>
</table>

The results of the assessment of working memory indicate significant differences in the functioning of the verbal, visuo-spatial and central executive components of James’s working memory system. Measures of the functioning of the visuo-spatial and central executive components of working memory fell within the average range, while measures of the functioning of the phonological loop component fell within the low average to below average range. Broadly, this working memory assessment profile falls within Pattern 1 of the profile of working memory functioning described in Chapter 3. This pattern was below average phonological loop functioning, average visuo-spatial functioning and average central executive functioning.

Thus, in the case of James it has been possible to identify limitations in the functioning of the phonological loop component of his working memory system. In the second part of Stage 1 of the study individual differences in James’s working
memory profile were used to inform the trialling and evaluation of a scaffolded concept-mapping process that could be used to assist James with the development of his understanding of the information contained in a science textbook chapter. This part of Stage 1 of the study was implemented through a series of four trials using a cyclic process of design, implementation, evaluation and redesign.

4.2 The Development of Scaffolded Concept Mapping with James

When concept mapping is used to summarise a chapter of a science text, before students can generate the concept map they are required to process the large amount of verbal information contained in the text. The results of James’s working memory assessment indicated that the functioning of the phonological loop component of his working memory system fell within the low to below average range. In Chapter 2 limitations in the functioning of the phonological loop component of working memory were linked to difficulties with vocabulary knowledge (Baddeley et al., 1988; Cain et al., 2004; Gathercole, 1990), sentence memory (Mann et al., 1980) and language comprehension (Fieback et al., 2004; Just & Carpenter 1992; Lieberman & Shankweiler, 1985; Mann et al., 1989). The span tests that were used to this component of working memory are thought to provide a measure of the storage and rehearsal of verbal information in working memory (Pickering, 2006). James’s difficulty with the storage and rehearsal of verbal information in the phonological loop component of working memory has the potential to have a significant impact on the processing of verbal information during the information extraction phase of concept map construction and in turn, on the development of the final whole-chapter concept map.
The suggestion that students who experience difficulty with learning, experience difficulty with the extraction of information from text is supported by Garner and Alexander (1989). Also a study by Winograd (1984) found that poor readers who experience difficulties with reading comprehension differed from good readers when summarising passages from expository texts in what information they considered to be important, in what they included in their summaries and in how they transformed the textbook information into the gist of the passage. Cain et al., (2004) found that children with poor comprehension skills experienced difficulty in inferring the meaning of new vocabulary items from text particularly when required to integrate several ideas that were spaced throughout the text. Guastello et al., (2000) reported that students with learning difficulties also have difficulty in understanding the patterns in expository text and in using the logical order of textual ideas and concepts to facilitate their reading of texts.

It has been argued that if students encode highly related information through both the verbal and visual modes that this multi-modal encoding of the incoming information may reduce cognitive load and as a result enhance the processing of the information (Sweller et al., 1998). The value of the integration of the visual and verbal modes of representation in science learning has become a feature of the recent science education literature (Hand & Prain, 2006; Yore & Treagust, 2006). A second means of enhancing the encoding incoming information is through the use of a variety of elaborative instructional components that foster the formation of additional representations in memory (Pressley et al., 1987). In Trials 1-4 of the study, a number of different sequences and combinations of scaffolding techniques that were used to enhance the multi-modal processing and elaboration of the conceptual information in
working memory were put to trial and evaluated. It was proposed that by improving the encoding and processing of conceptual information in working memory, the process of concept map construction would be facilitated.

4.2.1 Design of Trial 1

In Trial 1, scaffolding was provided in the form of a pre-prepared concept list, student-constructed written concept statements and responsive elaboration. The pre-prepared written concept list was used to assist James’s visual search in locating the key concepts in the text (Novak & Canas, 2006). The written definition statements were used to provide him with an opportunity to visually review (Meiers & Knight, 2007) and verbally rehearse (Pressley et al., 1987) the verbal information that was contained in the text. Responsive elaboration (Duffy & Roehler, 1986) was used to provide corrective verbal feedback to James when he had developed his concept statements. Through the use of a series of how, why and what questions, the interactive dialogue associated with the use of responsive elaboration focussed on assisting James in isolating key concept-related information in the text, in clarifying his misconceptions about the information contained in the chapter, in rating the level of importance of the information that he had selected, in encouraging him to develop a more detailed concept statement, and in reflecting on the meaning conveyed in his written answers.

When James was assessed using the Working Memory Assessment Battery he was found to have below average functioning of the phonological loop. In this trial, it was thought that the provision of additional levels of predominantly verbal scaffolding would assist with the elaboration of information in working memory and as a result
assist James with the consolidation of his knowledge of key concepts and with the development of conceptual links during the process of map construction.

4.2.2 Implementation of Trial 1

Trial 1 was conducted using a textbook chapter entitled “Electricity” over a period of seven one-hour learning support sessions. During this time James also studied the science chapter in his class lessons.

James was provided with a list of the key concepts from the chapter on electricity and was then required to develop a written summary statement for each of these concepts. To do this, James was asked to read the textbook until a key concept was identified and then write a short statement about each concept that summarised the key ideas contained in the text. James was told that this statement could take the form of a series of dot points or a series of short sentences. As James worked through the concept list, the researcher read through each of his summary statements and James was given corrective feedback about each of his answers using a responsive elaboration. James was given the opportunity to complete the concept statements independently before this feedback was given.

When all of the concept statements had been completed James was asked to use the concept list to develop a concept map for the chapter. This concept map was drawn freehand on a blank piece of paper.
4.2.3 Evaluation of Trial 1

The inferences drawn by the researcher in the evaluation of Trial 1 are based on the researcher’s interpretation of the work samples produced by James during the tutorial sessions and of the dialogues that occurred between James and the researcher during these sessions.

During Trial 1 James experienced a high degree of difficulty with the completion of the concept statements. In particular, after reading the textbook, he found it difficult to identify the important concept-related information in the text and then to represent this information in a written concept statement. The resulting concept statements usually did not contain the number of key ideas contained in the text. Figure 4.1 represents an example of a concept statement written by James in response to the key concept of “parallel connection” contained in the chapter about electricity.

Figure 4.1. Written concept statement for the concept of “parallel connection”.

The concept statement reads as follows “when two bulbs on a circuit can be connected side by side it is a parallel connection and different wires splits and follows different paths. two Bulbs same brightness.”
The key ideas relating to “parallel connection” that can be identified in the science text are that the two bulbs are connected side by side, that the electrons going through each bulb get a full push from the cell, that there is no sharing of the current and that each bulb glows as if there was only one in the circuit. It had been expected that by referring to the textbook, James would have identified and communicated meaningfully in written form these four key ideas. Reference to Figure 4.1 indicates that James only identified and represented in written form the first and last of these key ideas.

It can also be noted by inspection of the work sample in Figure 4.1 that James experienced considerable difficulty in demonstrating his understanding of “parallel connection” in the written summary statement. The boundaries of individual statements are unclear and words have not been combined into meaningful units in sentences. There is limited and incorrect use of punctuation and capitalisation and the statement contains a number of spelling errors. As a result, it is difficult to identify the precise meaning of the information contained in the answer, as overall the statement lacks cohesion and conciseness of thought. The work sample suggests that James has found the task of concept statement construction overwhelming. In addition, the construction of the statement required a considerable amount of assistance from the researcher. James often had to be reminded to stay on task during the construction process. Overall his level of engagement with the task lacked commitment and enthusiasm.

The responsive elaboration strategy was useful in encouraging James to process the conceptual information contained in the text more deeply. However, because he often
required a considerable amount of intensive concept clarification by the researcher, the high degree of verbal intervention that was required often seemed overwhelming to James and he did not always use the information that had been discussed to improve his written summary.

The first concept map that was drawn by James using the concepts on the concept list had a basic structure that contained only a few simplistic or incorrect conceptual links. This concept map is shown in Figure 4.2.

![Concept Map for Electricity](image)

**Figure 4.2.** Concept map for the chapter entitled “Electricity”.

The essential feature of this concept map is that it is drawn in keeping with the spoke structure described by Kinchin et al. (2000). That is, it is a radial structure in which all of the secondary concepts are linked to the core concept. While James constructed a basic set of verbal and spatial relationships between the concepts, he did not articulate
the conceptual links between the concepts in such a way that he demonstrated a high level of conceptual integration and understanding. Sub-concepts such as “electric current”, “electric charges” and “circuit diagram” link directly to the core concept of “electricity”. This suggests that this knowledge has only been formed in relation to this one core concept.

Some examples of conceptual relationships represented on the concept map such as “electric current is measured in amperes” and “electricity flows by electric current” represent a good level of conceptual understanding of the relationship between these concepts. However, a number of conceptual relationships represented on the map give an indication of the level of difficulty that James experienced with both the placement of concepts and with the development of conceptual links. For example, by connecting “electricity” directly to “electric forces” and simply connecting them by the verb “has”, James demonstrated that he had little understanding of these two concepts. Also the attempted link between “electrical resistance” and “circuit diagram” contained no linking statement. The nature of these conceptual links reflects the state of non-learning referred to by Hay (2007).

When the concept map had been completed, the structure of the map was discussed with James. During this discussion process James spontaneously rated his performance as five out of ten. It was agreed to attempt to revise the map. During this process of map revision, the researcher worked with James using responsive elaboration, to clarify the meaning of some of the concepts, to evaluate the accuracy of meaning that had been conveyed through the linking words on the map and to reposition the concepts within the map so that more meaningful conceptual links
could be formulated. It was evident to the researcher during this process that James did not have a clear knowledge of the key concepts contained in the text.

Because of the level of student frustration that was associated with the constant need for map revision during the interactive discussion process that occurred between James and the researcher, two additional scaffolds that have been used in research studies to assist with map construction were added at this time during Trial 1. Firstly, the key concepts contained on the concept list were placed onto individual concept cards so that the initial positioning of the concepts that were to be linked on the map could be made more easily (Novak et al., 1983; White & Gunstone, 1992) and secondly, Inspiration 6 (Helfgott & Westhaver, 1998) was used to replace the pencil and paper method of revising the representation of the map structure after the concept cards had been positioned.

The cutting of the concept list into individual concept cards provided James with a way of physically reorganising the concepts before they needed to be committed to the computer-generated map. He enjoyed using the concept cards and this process added a visuo-spatial dimension to the encoding of the verbal information. James used Inspiration 6 to make alterations to the map under the guidance of the researcher using the responsive elaboration strategy.

The use of Inspiration 6 had a noticeable impact on the effective use of the responsive elaboration strategy. The visual structure of the map provided a flexible template that could be continually refined in keeping with the responses provided by the student. The provision of corrective feedback by the researcher was less frustrating to James.
He became more involved in the correction process and this in turn allowed the researcher to give an improved level of guidance and explanation in order to assist him with the reorganisation of the map and with the construction of meaningful linking statements. Through the combined use of the concept cards and Inspiration 6, James became more involved with the map construction process and was more likely to engage in the level of evaluative thinking that was required to formulate the relationships between the concepts. The final map produced by James is given in Figure 4.3.

![Figure 4.3. Final concept map for the chapter entitled “Electricity” drawn using Inspiration 6.](image)

The positioning of the concepts and the conceptual links represented in this map are a result of the interactive dialogue that occurred between James and the researcher during the process of map revision. While some of the linking statements; for
example, “electrons which is known as electric current” do not provide a precise description of the conceptual relationship that exists between these two concepts, the map provides a point in time representation of the student’s responses in the use of the responsive elaboration strategy. The development of linking statements was constrained by the considerable difficulty that James encountered when he was attempting to formulate the language required to demonstrate his understanding of the relationship between concepts.

4.2.4 Design of Trial 2
In Trial 1, despite the use of scaffolding activities that included the use of key concept lists, the completion of written concept statements and interactive discussion using responsive elaboration, James experienced a considerable degree of difficulty with both the extraction of conceptual information from the text and with the process of concept map construction. Also, he had not developed a good knowledge of the concepts contained in the chapter. At this time it was hypothesised that one factor that may have contributed to these difficulties was the level of conceptual difficulty associated with the information contained in the chapter about electricity. It was decided to repeat the procedure with the next chapter entitled “Food for Life”.

4.2.5 Implementation of Trial 2
Trial 2 was conducted over a period of seven one hour learning support sessions. During this time James also studied the science chapter in his classroom. In keeping with the procedure followed in Trial 1, a hand-drawn concept map was constructed when all of the written concept statements had been completed. However, in contrast
to the procedure followed in Trial 1, individual concept cards were provided for use while this map was drawn. This hand drawn-map was then converted to a computer-generated map using Inspiration 6. The computer-generated map was then used as a basis for further map revision using responsive elaboration.

4.2.6 Evaluation of Trial 2

While James did exhibit greater familiarity with the subject material contained in this chapter, the same difficulties relating to the extraction and representation of the conceptual information contained in the text emerged. Some of the written concept statements produced by James during Trial 2 are shown in Figure 4.4.

Figure 4.4. Written concept statements for the concepts of cell respiration, plasma and capillaries.
The concept statements read as follows: Cell respiration - “the process that happen when food Brochen down and release energy”, Plasma - “pale yellow liyuid part of blood mainly contains water helped dissolved food and waste products from cells” and Caplliaries – are small one cell thik wall which Join arteries to the vieas.”

For the concept of “cell respiration” it was expected that James would identify and represent three key ideas contained in the text. These were that cell respiration is a process of obtaining energy from food, that the chemical energy contained in food is transferred to other molecules and that the energy is used for activities such as muscle activity. Reference to Figure 4.4 indicates that James only identified one of these key ideas. Once again the writing samples reveal difficulties with spelling, capitalisation and punctuation. While the statement that relates to “plasma”, contains a number of elements of the key ideas contained in the text, James did not combine this information into a syntactically-correct concept statement that reflected either cohesion or conciseness of thought. For the sub-concept “capillaries” the text contained four key ideas. Of these, James identified one.

The hand drawn concept map is shown in Figure 4.5.
The chapter was entitled “Food for Life” and James placed this title at the centre of his concept map. However, during the construction of the map he modified his initial choice to “food”. As in Trial 1, the map drawn by James took the form of a simple spoke structure with the majority of the sub-concepts linked to the central main concept. While the material contained in this chapter was more familiar to James, unlike the sub-concepts contained in the chapter about electricity, this chapter provided a further challenge in that it contained a more diverse set of sub-concepts.
Inspection of the map suggests that James experienced considerable difficulty with the positioning of the sub-concepts and he did not differentiate which of the sub-concepts could be linked directly to “food”. The concept map does indicate a basic understanding of the relationships that exist between food and the functioning of the digestive system. This is demonstrated by relationships such as “food broken down by enzymes” and “four main food types which are fats, vitamins/minerals, proteins, carbohydrates”. In some cases, even when a potential link had been established for example “food uses digestion” James did not demonstrate through his choice of linking statement a high level of understanding of the relationship between the concepts. These difficulties associated with the clarity of conceptual understanding and with the formulation of the language necessary for link construction can also be seen in conceptual relationships such as “cell respiration produces energy lungs” and “food uses oxygen in lungs”.

In an attempt to overcome these difficulties with map construction, it was decided at this time in Trial 2 to break the process of map construction into a number of smaller steps. A small section of the hand-drawn map was selected for re-evaluation. The jointly-constructed concept map that was produced using the first set of concepts is shown in Figure 4.6.
This map provides a further indication of the difficulties associated with link construction. During the re-evaluation of this part of the map, James experienced difficulty in articulating to the researcher, his knowledge of some of the sub-concepts. This was particularly evident when he was attempting to discuss the relationship between food, the kidneys and excretion and also the relationship between digestion and the lungs. He was unsure of the functions of these organs and experienced difficulty developing linking statements and repositioning the concepts on the map. The use of the concept cards was only useful in repositioning the sub-concepts when James had a good knowledge of the sub-concepts involved.
Inspection of the map also provides an example of a further difficulty associated with link construction. This difficulty can be seen in the conceptual relationship that has been developed between “lungs’ and “alveoli and trachea”. When formulating the linking statement “part of the lung is”, James experienced difficulty when he attempted to reorganise the linking statement so that the sub-concept “lung” could be eliminated. One possible explanation of this observation is that James was finding it difficult to manipulate the information contained in the conceptual relationship in working memory.

In both Trial 1 and Trial 2, James experienced difficulty in identifying the key concept-related information from the text, in maintaining attention during the extraction process and in representing this information in the form of a meaningful written concept statement. During the process of concept statement construction James, required a high level of clarification from the researcher and attempts to provide verbal feedback using the strategy of responsive elaboration resulted in a high level of frustration for the student. In addition, when James was required to construct a concept map it was evident that he did not have a good knowledge of the concepts contained in the text. Also, this scaffolding of the knowledge construction process did not translate into an improvement in James’s independent formulation of meaningful conceptual links on the concept map.

In Trial 1 and Trial 2, it had been noted that when the strategy of responsive elaboration was used while the concept maps were being revised using Inspiration 6, James was more likely to focus on the verbal information being discussed. Also, when James was assessed with the Working Memory Assessment Battery he was found to
have average to above average functioning of the visuo-spatial component of working memory. Because of these observations and the fact that the high level of predominately verbal scaffolding used in Trials 1 and 2 had failed to provide James with the good level of conceptual knowledge that was required during concept map construction, an increased level of visual scaffolding was included in the instructional approach used in Trial 3. It was proposed that the increased multi-modal encoding of conceptual information would improve James’s knowledge of conceptual information and enhance meaningful link formulation.

4.2.7 Design of Trial 3

In Trial 1 and Trial 2 of this investigation, it was hypothesised that in order to facilitate the development of conceptual understanding during the process of concept map construction, the use of a combination of verbal and visual scaffolding in the form of concept lists, student-constructed written concept statements and researcher-directed responsive elaboration would enhance the encoding of the conceptual information contained in the text, and as a result facilitate the processing of conceptual information in working memory during the process of concept map construction. In Trial 1 and Trial 2, it was evident that the amount of verbal processing that was required for James to extract and represent the conceptual information contained in the text, had proved overwhelming. Consequently, he experienced difficulty with the recall of this information when it was required for map construction. The evaluation of Trials 1 and 2 indicated that despite the level of scaffolding that had been provided, James continued to experience difficulty with both the extraction of information from the text and with the recall of this information when it was required for map construction.
In Trial 3, as well as the use of written concept statements and responsive elaboration to assist the encoding of textual information, two additional scaffolding activities were included. The first of these took the form of spoke word maps. These maps were constructed by placing the key concept in the centre of the spoke with up to five key ideas relating to that concept, radiating from it. No linking words were required in this structure (Kinchin et al., 2000; Young, 2005). It was thought that an additional level of visuo-spatial scaffolding would increase the depth of processing associated with the encoding of conceptual information from the text. These word maps were constructed using Inspiration 6.

The second change to the scaffolding process that was included in Trial 3 was the decision to group the concepts into subsets and then to require James to construct a smaller concept map for each subset before the construction of the final concept map was attempted. It was hypothesised that this would further reduce the cognitive load associated with map construction and that this reduction in cognitive load may impact on the process of link construction. These maps were constructed using Inspiration 6. In addition to providing an additional level of visual scaffolding, Inspiration 6 was used to increase James’s level of motivation for the task and to assist him in focusing his attention. Individual concept cards were not used in this trial as it was anticipated that their use in assisting James to have flexibility in re-organising the placement of the concepts on the map could be just as well achieved through the use of Inspiration 6.
4.2.8 Implementation of Trial 3

Trial 3 was conducted using a biology chapter entitled “Building Blocks of Life” over a period of nine learning support sessions. James was provided with a list of the key concepts contained in the chapter that had been grouped into a number of concept subsets and asked to use Inspiration 6 to develop a spoke word map for each concept in the subset. This was done directly after reading the specific part of the text that related to each of the concepts. When all of the spoke word maps for the subset of concepts had been completed, James was required to complete the written concept statement for each of the concepts.

In order to evaluate the impact of this additional level of visuo-spatial scaffolding on James’s recall of the concept-related information, when James had completed all of the concept statements in the subset he was asked to construct, from memory, a spoke word map for each concept. James was then asked to construct a concept map for the concept subset. This concept map was drawn using Inspiration 6. This process was repeated for each concept subset. These maps were then integrated to form a concept map for the whole chapter.

4.2.9 Evaluation of Trial 3

The use of the spoke word maps to facilitate the extraction of the key concept-related information from the chapter had a marked impact on the ease to which James identified and represented the key ideas in the text. The word maps provided him with a clear visual representation of the key ideas that had already been identified and he was then able to look back and check if he had included all of the important information in his map. During the extraction process James worked more
independently. He maintained a high level of engagement and he required less verbal feedback and encouragement from the researcher.

On those occasions when the researcher was required to give verbal feedback about James’s current word map, the flexibility associated with the use of Inspiration 6 provided James with a means of altering his answers easily as he worked through the process of clarifying his understanding. During this process of map revision James was more actively involved in the clarification process and was more focused on the task. As a result of these factors there was more opportunity for the effective use of responsive elaboration, which in turn provided increased opportunity for the rehearsal and elaboration of the conceptual information contained in the text.

When James used the word maps to produce the written concept statements, he produced statements that provided a more comprehensive summary of the important information contained in the text. There was a marked improvement in his use of spelling, sentence structure, punctuation and capitalisation and the sentences that he constructed reflected greater cohesion and conciseness of thought. An example of a spoke word map and associated concept statement for the concept of “cytoplasm” is shown in Figure 4.7.
When James was asked to recall the key concept-related information by drawing spoke concept maps, he recalled more readily the detail that was related to each of the key concepts and spontaneously formulated meaningful links on the spoke maps. For example “vacuoles store water/dissolved substances”. An example of spoke word maps and associated recalled maps is provided in Figure 4.8. The recalled maps also provided a way of identifying James’s ongoing misconceptions about the relationships between concepts. For example in the relationship “organelles have cytoplasm” James demonstrated little understanding of the relationship between these two concepts. This could have been written more correctly as “organelles are found in the cytoplasm”.

Figure 4.7. Spoke word map and written concept statement for the concept of “cytoplasm”.

Cytoplasm

Cytoplasm is a jelly like substance that fills the inside of a cell. Cytoplasm is inside a cell. In the cytoplasm many chemical reactions take place here. Also contain many other small cell structures.
Figure 4.8. Spoke word map and associated concept map for the concepts of organelles and vacuoles.

When James was asked to develop this knowledge of all of the concepts contained in the first subset into a concept map he produced the spoke concept map shown in Figure 4.9.
In this map James organised the five concepts into a structure that linked the concepts in a potentially meaningful way. However in his selection of linking words, it was evident that he had limited understanding of the relationships that exist between the concepts. For example “have” has been used to explain the link between “cells” and “cytoplasm” and “cells” and “cell membrane”. The relationships between these concepts could have been differentiated further by the choice of “contain” in the case of “cells” and “cytoplasm” and by the choice of “are surrounded by a” in the case of “cells” and “cell membrane”.

When asked to construct the map for the second concept subset James, linked the concepts through the chain concept map shown in Figure 4.10. In this map James did not link the concepts in a potentially meaningful way or formulate meaningful verbal links between the concepts.
In Trial 3 the combined use of verbal and visuo-spatial scaffolding in the form of spoke word maps, written concept statements and responsive elaboration improved James’s knowledge and recall of the key concepts contained in the text. This improved knowledge of the concepts also enhanced his formulation of links on the spoke concept maps that James constructed independently to represent his recall of the text-related information. However when James was required to transfer his knowledge of individual concepts into an integrated concept map for a concept subset, the links that he constructed did not reflect a high level of conceptual understanding. James experienced difficulty with the construction of the subset concept maps in three ways. Firstly, in identifying which concepts could be linked; secondly, in formulating the language of a possible conceptual link; and thirdly, in judging if a meaningful link had been formulated. Because of these difficulties with link construction, further changes were made to the scaffolding process used in Trial 4.
4.2.10 Design of Trial 4

In Trial 3, while the additional level of visuo-spatial scaffolding provided by the introduction of the spoke word maps had a considerable impact on James’s knowledge of the key concepts contained in the text, James continued to experience a considerable degree of difficulty when attempting to formulate meaningful links on the concept maps. Before he could decide if a link was even possible, James had to select two concepts, formulate a verbal link and then decide if a meaningful link had been constructed. While in Trials 1 and 2 concept cards had been used to aid the process of deciding which concepts could be linked, the use of the concept cards had proved to be very time consuming. In Trial 3 the use of concept cards was replaced by the use of Inspiration 6. The use of this program did not overcome the difficulties associated with concept placement. In order to overcome the difficulties with link construction three design improvements were added to Trial 4.

Firstly, in order to overcome the difficulties associated with James having to decide which of the concepts could be related, a partially-completed concept map was constructed for the whole science chapter similar to those described by Chang et al. (2002). To do this the chapter was divided into three concept subsets, which formed the basis for the construction of the map. The whole-chapter partially-completed concept map took the form of a network of concepts as described by Kinchin et al. (2000), with named nodes that required James to provide the conceptual linking statements. The map was constructed so that it could be completed in a number of stages. It was thought that the provision of this level of scaffolding would reduce the cognitive load associated with James having to decide which of the concepts could be related.
Secondly, in Trial 3 it had been noted that when James became more familiar with the conceptual information contained in the chapter, he formulated links spontaneously on the recalled spoke word maps. In Trial 4 it was decided to add a step that required the conversion of spoke word maps to spoke concept maps. The inclusion of this step provided an opportunity for the construction of semantic word maps similar to those used by Bos and Anders (1990) to improve vocabulary knowledge. Also because James had experienced difficulty in monitoring the construction of meaningful links on the concept maps, the process of mental modelling (Duffy et al., 1988) was used in conjunction with responsive elaboration to provide James with an opportunity to gain a greater awareness of the process of meaningful link construction within a more controlled knowledge framework. This step required James to convert each spoke word map to a spoke concept map before he completed the written statements. It was thought that this additional opportunity for language elaboration, combined with the associated feedback and mental modelling provided by the researcher, might improve James’s monitoring of whether or not he had formulated meaningful links on the concept maps.

Finally, in order to investigate further the impact of the scaffolded concept-mapping process on the development of James’s conceptual understanding, when the final whole-chapter concept map had been completed, James was required to represent this understanding in written form by answering a number of conceptual questions that related to the information contained in the chapter. These questions took the form of the extended recall conceptual questions described by Gunel et al. (2007).
It was thought that the use of the combined scaffolding sequence of spoke word maps, spoke concept maps, written concept statements, responsive elaboration, mental modelling and the partially-completed concept maps would provide an increased opportunity for James to process and represent the textual information through both the verbal and visuo-spatial modes (Hand & Prain, 2006; Sweller et al., 1998) and that the use of this scaffolding sequence would have a significant impact on both the process of link construction and the development of conceptual understanding.

4.2.11 Implementation of Trial 4

Trial 4 was conducted using a science chapter entitled “Living with Acids and Bases” over a period of nine learning support sessions. James was provided with the list of key concepts developed for the science chapter. This list consisted of three concept subsets. Using the first concept subset, James was asked to read the text and to develop a spoke word map for each concept using Inspiration 6. This word map was then converted to a spoke concept map.

When the spoke concept maps for each concept in the subset had been completed, James completed the written concept statements for each of the concepts in the subset. James was then provided with the pre-prepared template of the partially-completed concept map for the concept subset and asked to complete the linking statements between the concepts. This process was repeated using the second and third concept subsets. The concept maps for each concept subset were combined to form the whole chapter concept map. When the concept map for the chapter had been completed James was asked to provide written answers for a number of extended recall conceptual questions that related to the information contained in the chapter.
4.2.12 Evaluation of Trial 4

In Trial 4 the two main concepts contained in the first concept subset related to information about acids and bases. For this concept subset James identified the key concept-related information from the text; however, when he was required to convert the information contained in the spoke word map into a spoke concept map James found it difficult to construct meaningful conceptual links even though the language that could be used to construct the links was contained in the bubbles of the word map. James needed to be reminded regularly to check if a meaningful link had been formulated, and he required a considerable amount of encouragement to persist with this monitoring process. The advantage of using Inspiration 6 at this time was that it made it easier for James to make and visualise the changes that needed to be made to the linking statements and then to check if they were meaningful. The flexibility associated with use of Inspiration 6 made the process of link evaluation less frustrating for the student.

The second concept subset contained three concepts. These were indicator, pH scale and ion. The concepts contained in this subset were more complex and required James to sort out larger portions of the text. For this concept subset James experienced greater difficulty sorting the information into the spoke word maps. The sorting of the information that related to the concept “ion” caused greatest difficulty. Figure 4.11 provides an example of a series of word and concept maps that were produced by James while attempting to extract and reorganise the information that related to the concept of an “ion”.

Figure 4.11. Series of word and concept maps for the concept of an “ion”.

- An atom that has lost or gained an electron is no longer neutral.
- Atoms are metals and tend to lose electrons, forming cations.
- Non-metals tend to gain electrons, forming anions.
- Some atoms lose electrons while others gain electrons.
- Empty atoms contain electrons negatively charged.
- The nucleus in an atom contains hydrogen ions.
- The number of positively charged protons is the same as the number of negatively charged electrons.
- Atoms are metals and tend to lose electrons forming cations.
- Non-metals tend to gain electrons forming anions.
- Either case, an atom no longer neutral.
- An atom that has lost or gained an electron is no longer neutral.
- Empty atoms contain negatively charged electrons.
- The nucleus in an atom contains positively charged protons.
- The number of positively charged protons is the same as the number of negatively charged electrons.
- Atoms are metals and tend to lose electrons forming cations.
- Non-metals tend to gain electrons forming anions.
- Either case, an atom no longer neutral.

Figure 4.11. Series of word and concept maps for the concept of an “ion”.
In the first of the three diagrams James identified ten pieces of information contained in the text. While some of this information can be related to the concept of an ion; for example, “some atoms lose electrons while others can gain electrons”, many of the key ideas cannot; for example, “atom is also neutral”.

In the second diagram James began to convert the information that had been represented in the form of a spoke word map into a spoke concept map by developing linking statements. During the first step in this process, James used the information that he had extracted from the text to isolate a key idea that he thought could be connected to the central concept by a linking statement. When this conversion was completed, each of the concepts and the associated linking statements were discussed with James in order to establish whether the links between the concepts were meaningful. It was during these interactions between James and the researcher that it became evident just how much difficulty James was experiencing with meaningful link construction.

During the conversion of the word maps to the concept maps, it was also evident to the researcher that James had a number of misconceptions about the structure of atoms and how the structure of an atom is related to that of an ion. The revision of the spoke concept maps provided an opportunity for the researcher to clarify James’s knowledge of the basic structure of the atom and then to differentiate his understanding of the structure of an atom from the structure of an ion. During these discussions between James and the researcher, James decided that some of the information could be eliminated from the map. The third diagram in the series represents the student’s final concept map for an “ion”.

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The final concept map for the chapter is shown in Figure 4.12. Even though the template provided for the student had positioned and named each node, James still required assistance with some of the linking statements. Without assistance from the researcher James would not have developed the links of “pH value measured using an indicator” or “pH value gives us H+ ion concentration”. He did not develop independently the portion of the map that relates to acids, bases and an indicator.

Figure 4.12. Overall concept map for the chapter entitled “Living with Acids and Bases”.

Figure 4.13 provides a sample of an answer written from memory by James to one of the extended recall conceptual questions that was completed after the whole-chapter concept map had been constructed.
1. Normal rainwater has a pH of about 6, distilled water has a pH of 7 and acid rain can have a pH of as low as 2. What does the pH value tell you about the concentration of hydrogen ions in each of the water samples?

![Figure 4.13. James’s independent written response to an extended recall conceptual question.](image)

The answer to the question reads as follows. “There are a few hydrogen ions in normal rain water, there are no h Ions in distilled water and lots of H Ions in acid rain.”

In this answer James demonstrated an understanding of the relationship between the pH value and the hydrogen ion concentration in a range of water samples. He did not spontaneously monitor his written answer, but when he was reminded to do so he added the statements relating to hydrogen ions. In this answer James has also demonstrated an improved use of spelling, capitalisation and punctuation and has presented this information in a written sentence that reflects cohesion and conciseness of thought. In answering this question, James was also provided with an additional opportunity to clarify his understanding through the re-representation of the information that related to the concepts of acid, pH scale, ion and acid rain.
4.3 Summary of Stage 1 of the Study

The central aim of Stage 1 of the study was to develop a scaffolded concept-mapping process that would enable James to develop and represent his understanding of the information contained in a science textbook chapter. The implementation and evaluation of Trials 1, 2, 3 and 4 identified a number of specific difficulties experienced by James during the process of concept map construction. In Trial 1 and 2 it was evident that even before the construction of the map could be attempted, James was experiencing a considerable degree of difficulty with the extraction and representation of the key concept-related information from the text. During these trials it was also evident that James was experiencing difficulty with the recall of concept-related information, with the identification of concepts that could be related and with the formulation of meaningful conceptual links on the concept map.

In Trial 3 the introduction of the construction of a spoke word map using Inspiration 6, enabled James to extract the information from the text more independently, to maintain his focus and interest, and to monitor his progress during the extraction process. Following the completion of the spoke word maps in combination with the written concept statements, James recalled more readily the information contained in the text. However, despite this level of scaffolding James still experienced a considerable degree of difficulty when asked to transfer this knowledge to a situation where he had to decide which concepts could be linked and in formulating meaningful conceptual links between concepts. The process of link construction was proving to be very time consuming and frustrating for James.
In Trial 4 an attempt was made to overcome the difficulties with link construction in two ways. Firstly, James was required to convert the spoke word maps to spoke concept maps through the use of mental modelling and responsive elaboration to assist with the process of link construction. Secondly, James was provided with partially-completed concepts maps that could be completed and combined to form the whole-chapter concept map.

While James continued to experience difficulty with the formulation of links on the partially-completed concept maps, the introduction of the step that required him to convert the spoke word map to the spoke concept map did ensure that James had to process the text-related information more deeply and provided the researcher with a more structured framework that could be used to clarify misconceptions about the concept-related information contained in the text. The provision of the partially-completed concept maps eliminated the need for the time consuming and frustrating process that required James to propose which concepts could be linked on the map, but did not eliminate the difficulties that he encountered with link construction. The formulation of links on the concept maps required a very high level of corrective feedback between James and the researcher through the use of both mental modelling and responsive elaboration.

In Trial 4 the combined use of scaffolding techniques in the form of spoke word maps, spoke concept maps, written concept statements and partially-completed concept maps, combined with the use of mental modelling and responsive elaboration during concept map construction, provided James with sufficient assistance to demonstrate an integrated understanding of some of the concepts contained in the
chapter. This understanding was evident when he was required to provide a written answer to the extended recall conceptual questions.

The most significant features of the scaffolded concept-mapping process that was developed during Stage 1 of the study were:

1. The provision of a list of the key concepts that had been grouped into concept subsets.
2. The joint construction by James and the researcher, of spoke word maps and spoke concept maps using Inspiration 6, responsive elaboration and mental modelling.
3. The completion of the student-constructed written concept statements
4. The joint construction of partially-completed concept maps for each concept subset using Inspiration 6, responsive elaboration and mental modelling.
5. The completion of the whole-chapter concept map.
6. The independent completion of extended recall conceptual questions.

In Stage 2 of the study, this approach to the scaffolding of the concept-mapping process was re-evaluated with a second student who was experiencing difficulty with science learning. The results of this stage of the study are discussed in Chapter 5.
CHAPTER 5

Stage 2: The Re-evaluation of Scaffolded Concept Mapping with Sam

Stage 1 of this study was conducted with James who had been referred to Learning Support because of the difficulties that he was experiencing with learning in his core subject areas, one of which was Science. In this stage of the study, James was assessed using a *Working Memory Assessment Battery*, to identify any individual differences in his working memory functioning. This assessment information was then used to guide the development of a scaffolded concept-mapping process. In Stage 2 of the study, this sequence of the assessment of working memory functioning and the evaluation of the scaffolded concept-mapping process was implemented with a second student Sam also referred to Learning Support because of difficulties he was experiencing with learning in core subject areas, including Science.

Stage 2 of the study was conducted in two parts. Firstly, Sam was assessed using the *Working Memory Assessment Battery*. Secondly, the scaffolded concept-mapping process used in Trial 4 of Stage 1 of the study was re-evaluated by the researcher while working with Sam over two units of work. These trials are referred to as Trial 5 and Trial 6.
5.1 The Development of Sam’s Working Memory Profile

5.1.1 Sam’s Working Memory Assessment Summary

Sam was assessed with the Working Memory Assessment Battery that aimed to measure the functioning of the phonological loop, visuo-spatial sketchpad and central executive components of his working memory. The results of Sam’s working memory assessment are shown in Table 5.1.

Table 5.1

<table>
<thead>
<tr>
<th>Component of Working Memory</th>
<th>Name of Test</th>
<th>Level of Functioning Scaled Score</th>
<th>Level of Functioning Descriptor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phonological Loop</td>
<td>Digits Forward</td>
<td>5</td>
<td>Below Average</td>
</tr>
<tr>
<td>Phonological Loop</td>
<td>Auditory Word Memory</td>
<td>7</td>
<td>Low Average</td>
</tr>
<tr>
<td>Visuo-spatial Sketchpad</td>
<td>Visual Sequential Memory</td>
<td>13</td>
<td>High Average</td>
</tr>
<tr>
<td>Visuo-spatial Sketchpad</td>
<td>Abstract Visual Memory</td>
<td>9</td>
<td>Average</td>
</tr>
<tr>
<td>Visuo-spatial Sketchpad</td>
<td>Memory for Location</td>
<td>12</td>
<td>High Average</td>
</tr>
<tr>
<td>Central Executive</td>
<td>Semantic Organisation</td>
<td>9</td>
<td>Average</td>
</tr>
<tr>
<td>Central Executive</td>
<td>Visual Matrix</td>
<td>8</td>
<td>Low Average</td>
</tr>
</tbody>
</table>

The results indicate significant differences between the functioning of the phonological loop, visuo-spatial sketchpad and central executive components of Sam’s working memory system. Measures of the functioning of the phonological loop fell in the low average to the below average range. While there was some variability between subtests, in general, measures of the functioning of the visuo-spatial
sketchpad fell within the average range. Measures of the functioning of the central executive component of working memory fell at the lower end of the average range. In general, this assessment summary fits Pattern 1 of the working memory profiles described in Chapter 3. This pattern is below average functioning of the phonological loop, average visuo-spatial and central executive functioning. Thus, in the case of Sam it has been possible to identify significant individual differences in the functioning of the phonological loop component of his working memory system. This is the same general pattern that was identified for James.

5.2 The Re-evaluation of the Scaffolded Concept-Mapping Process

Because the profile of working memory functioning for both James and Sam were identified as fitting Pattern 1, it was predicted that Sam would experience the same difficulties with the concept-mapping process that been experienced by James. The most notable of these difficulties were the extraction of information from the text and the formulation and representation of linking statements on the concept maps.

5.2.1 Design of Trial 5

Sam was a student who was already familiar with the form and use of word maps and concept maps. However, he was provided with instruction to familiarise him with the process of concept map construction using Inspiration 6. Trial 5 was conducted using a science chapter entitled “The Living World” over four one hour learning support sessions. The scaffolded concept-mapping process that was implemented in Trial 5 followed a similar sequence to the one followed in Trial 4. However, because the implementation of the scaffolded concept-mapping process in Trial 4 had proven to be
very time consuming, it was decided to remove the step that required the Sam to construct a written concept statement for each of the key concepts. It was thought that this step may not be essential for the overall development of conceptual understanding and that through its deletion the scaffolding process may become less arduous and time consuming for the student.

5.2.2 Implementation of Trial 5

Sam was provided with the list of key concepts developed for the science chapter entitled “Living Things”. This list of concepts was divided into two concept subsets containing a total of six concepts. Sam was then asked to read the text and to develop a spoke word map for each concept in the first concept subset using Inspiration 6. Each spoke word map was to contain the key information that related to the concept in the text.

When the word maps for each concept in the subset had been completed and discussed with the researcher, Sam was asked to convert the word maps into spoke concept maps that contained linking words.

Because the chapter contained a total of only six key concepts, Sam was provided with a partially-completed concept map that contained all of the concepts included in the chapter and asked to complete this concept map without assistance. This map was discussed with the researcher.
Sam was then asked to provide, without assistance from the researcher, a written answer to an extended recall conceptual question that related to the information contained in the chapter.

5.2.3 Evaluation of Trial 5

When Sam was engaged in the task of identifying and representing the concept-related information on the spoke word maps he required varying degrees of assistance from the researcher. For those concepts such as “vertebrates” that were relatively familiar he completed the extraction process independently. For concepts such as “key” and “classification” where the concepts were more complex and less familiar Sam required more assistance in identifying and representing the main ideas in the text. When Sam was constructing the word maps he indicated that “this is better than writing them out”. This statement referred to his previous experience with writing concept statements directly from the text.

However, when Sam was asked to convert the spoke word maps into spoke concept maps he required a high level of assistance in formulating the linking statements. Figure 5.1 shows one of Sam’s attempts, for the concept of “structural characteristics”, to construct a spoke concept map from the information contained in the word map.
In these examples Sam did not develop meaningful conceptual links between the key concepts and the information contained in the bubbles. For the conceptual unit “structural characteristics things have lungs gills legs are structural characteristics”, it would have demonstrated greater depth of understanding for this proposition to be stated as “structural characteristics examples can be lungs gills legs”. In this example Sam did not demonstrate clarity of understanding in the conceptual link nor did he delete “structural characteristics” from the spoke bubble so that the conceptual unit as a whole became less repetitious. Also in the case of “structural characteristics is a way of classify organisms” he could have formulated the link “are used to” and in this way the statement would have represented greater clarity of understanding and represented the relationship between the two concepts at a more complex conceptual level.
Sam was required to complete the partially-completed concept map, he found it difficult to construct linking statements.

5.2.4 Design of Trial 6

During the implementation of Trial 5 the degree of difficulty that Sam was experiencing with the representation of meaning through the production and utilisation of language was becoming increasingly apparent. This was particularly the case when he was required to formulate, in his own words, the relationship between the key concepts and associated sub-concepts as a linking statement on the concept map. In Trial 6 it was decided to attempt to address some of these difficulties with the formulation and representation of language by re-introducing the step that required Sam to develop written concept statements after the completion of the spoke word maps.

5.2.5 Implementation of Trial 6

Trial 6 was conducted using a science chapter entitled “What Are Things Made Of” over twelve one-hour learning support sessions. Sam was provided with the list of key concepts that had been divided into four concept subsets each containing approximately six concepts.

He was then asked to read the text and to develop a spoke word map for each concept in the first concept subset using Inspiration 6. Each spoke word map contained the key information that related to the concept in the text.
When the word maps for each concept in the subset had been completed and discussed with the researcher, Sam was asked to convert the word maps into spoke concept maps that contained linking words. This step was conducted using Inspiration 6 and with assistances from the researcher using responsive elaboration and mental modelling. James then completed written concept statements for each concept in the subset.

Sam was provided with a partially-completed concept map that contained all of the concepts included in the subset and asked to complete this concept map without assistance. This map was developed in collaboration with the researcher using responsive elaboration and mental modelling.

This process was repeated until the first two concept maps were completed and combined to form one concept map. Sam was then asked to complete an extended recall conceptual question without assistance.

This process was repeated for the remaining two concept sets.

5.2.6 Evaluation of Trial 6

As in Trial 5, the degree of assistance that Sam required from the researcher during the process of extraction and representation of information from the science text onto the word map, varied with the conceptual complexity of the information contained in the text and with the positioning of that information in the text. When there were few sub-concepts or when the sub-concepts were fairly closely positioned in the text, Sam represented this information on the spoke word maps with minimal assistance from
the researcher. However when the number of sub-concepts was greater or more widely spread, a greater degree of clarification was required. Figure 5.2 shows Sam’s first attempt at representing the textual information that was related to the concept of “matter”.

Figure 5.2. Word and concept maps for the concept “matter”.
When Sam constructed this word map, sub-concepts that related more specifically to other key concepts in the subset were included on the word map. For example “gases is mainly nitrogen and oxygen” and “can also be helium and dioxide” could have been included in the map for “gases”. The process of converting this spoke map to a concept map provided an opportunity for the reorganisation of the sub-concepts that Sam had initially assigned to “matter”. In this way the sub-concepts that specifically related to matter could be simplified and reduced into a less complex visual template. The conversion process also provided a means through which the depth of processing of concept-related information could be improved.

When Sam was required to convert the word maps to concept maps he also required differing levels of assistance. In those cases during the conversion process when the relationship between the concepts was fairly simple, Sam either formulated the link independently or extracted it from the information in the word map bubble. An example of such a conversion can be seen in Figure 5.2 where Sam developed the conceptual unit “matter cannot change shape and volume easily”. However, in many cases, even though the word map contained the language that could be used to form the linking statement, Sam experienced difficulty in reorganising this information into a meaningful linking statement. Figure 5.3 shows the series of word and concept maps that were developed for the concept of “evaporation”.
Figure 5.3. Word and concept maps developed for the concept of “evaporation”.

Sam selected “evaporation” and “heating causes evaporation” from the text and represented the information on the first word map. When he attempted to reformulate this information on the concept map he represented it as “evaporation is heating causes evaporation”. Even though the key word “causes” was contained in the spoke
bubble Sam did not isolate this word from the text and identify its potential as a linking word that would be meaningful within the conceptual unit. Discussion with the researcher was required for Sam to reconsider whether his statement “heating is heating causes evaporation” was meaningful and for him to change it to “evaporation caused by heating”.

The use of Inspiration 6 during the process of link construction facilitated the reprocessing of the concept-related information from the word map to the concept map in a number of ways. Firstly, it aided the representation of the interactive dialogue that occurred between Sam and the researcher during the use of responsive elaboration. It did this by providing a visual template that could be referred to while Sam was re-evaluating whether the reconstructed links were meaningful. Inspiration 6 allowed Sam to make the gradual series of changes that arose during the interactive dialogue fairly easily and this encouraged him to participate in the process of self-correction. Without the flexibility associated with the use of the visual template provided by Inspiration 6, Sam would have found this process very frustrating.

Secondly, the visual template provided by Inspiration 6 provided a framework that could be used to clarify Sam’s understanding of the key concepts. In Figure 5.3, Sam selected “evaporation” and “the hotter it gets the quicker it evaporates” from the text. On the first concept map he formulated the linking statement “is when” and the resulting conceptual unit “evaporation is when the hotter it gets the quicker it evaporates” did not make sense. Further discussion with the researcher was required to develop the final conceptual unit of “evaporation is faster at high temperature”. The process of constructing a meaningful verbal relationship for each conceptual unit
required a very high level of scaffolding using both responsive elaboration and mental modelling.

When the spoke concept maps had been completed, Sam used these maps to complete the written concept statements. When completing these statements Sam commented that “the definitions made more sense and were easier to write”. This referred to the fact that previously he had been required to write the definitions directly from the textbook before completing the word and concept maps.

The difficulties that Sam was experiencing with the process of link construction became even more apparent when he was asked to complete the partially-completed concept maps. In the partially-completed maps, the concepts had been reorganised into a new and unfamiliar order. While he was highly engaged in the process of link construction, Sam required a considerable degree of assistance from the researcher to formulate meaningful conceptual links. Figure 5.4 shows an example of the fact that despite identifying that “mass can be measured using a balance” when he wrote the definition statement for “mass”, Sam did not bring these words to mind when he was required to propose a linking statement between “balance” and “mass” on the concept map.
In his first attempt at link construction, Sam proposed “mass can be weighed as a balance”. Sam was then asked if this statement reflected the meaning of the relationship between the two concepts. When questioned, Sam was aware that the link did not but, without assistance from the researcher, he did not formulate the language for a meaningful link. At this point in the discussion the researcher proposed a number of alternatives. When he was given some possibilities Sam chose the alternative that represented a more meaningful link. The final link of “can be measured using” is shown on the concept map in Figure 5.4.
When Sam had completed the partially-completed concept maps for the first two concept sets and these maps were combined to make one structure, Sam was then asked to provide a written answer, from memory, to extended recall conceptual questions that related to information in the first two concept sets. During the discussion with the researcher that followed, Sam indicated that “doing the maps helps to produce the language that is needed when you are writing the sentences”.

In order to evaluate how the scaffolded mapping process implemented in Trial 5 and 6 of this study may have impacted on Sam’s representation of conceptual understanding in written form a number of Sam’s writing samples were collected. The first of these was collected just prior to the commencement of Trial 5 when Sam had completed the in-class chapter test for the previous science chapter entitled “Mixing and Separating”. Sam’s learning of this chapter had relied solely on his class lessons and on his own personal study. He had not used a scaffolded concept mapping strategy or received assistance from Learning Support in his study of this chapter. The question and Sam’s written response is shown in Figure 5.5.

![Figure 5.5. Response to a textbook question without Learning Support intervention using scaffolded concept mapping.](image-url)
The answer to this question reads as follows. “When their two or more substances that called a condensation, when water is added it evaporates. This is called distillation.”

In answering this question Sam did not represent correctly any of the key features of the concepts of “condensation” or “evaporation” or give an explanation how each of these processes is used during “distillation”. While there is correct use of capitalisation and punctuation, words have not been combined into meaningful units in sentences and these sentences do not give an indication of cohesion and conciseness of thought. On the writing sample a number of darker words such as “called” and “added” can be seen. This represents places where Sam kept going over the word that he had written while he was trying to think of what to write next.

The second sample, shown in Figure 5.6, was collected when Sam had completed Trial 5 of the study for the science chapter entitled “The Living World”.

Explain how you could use a key to identify an unknown animal.

Figure 5.6. Writing sample for chapter entitled “Living Things”.

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The answer to this question reads as follows. “There is a couple of ways you can group (identify) a new animal into a key. Functional characteristics is one, in that if there warm blooded and if they no backbone. Another way of identifying it is if they have a vertebev (backbone) The would be called a structural characteristics. Also if they live on the ground or under the sea. If there related to any other species.”

In this writing sample Sam demonstrated a greater knowledge of some of the key concepts in the chapter. He named independently the concepts of “functional and structural characteristics” and provided some examples, although “no backbone” was identified incorrectly as a functional characteristic. He seemed to realise that the characteristics of an animal could be used to group and identify animals but his answer did not provide an explanation of how this information could be used in a key to identify an unknown animal. After completing Trial 5, Sam recalled more of the factual conceptual information contained in the science chapter and included this information in his written answer; however, he did not restructure the information when he was required to answer an extended recall conceptual question. While this written answer contains more factual information when compared with the response in Figure 5.5, the number of words that were altered and crossed out gives an indication of the degree of hesitancy with which it was written.

The third writing sample was collected when Sam had completed Trial 6 of the study and is shown in Figure 5.7.
1. (a) What is the name of the change of state that occurs when a small puddle of water disappears when the sun shines?

Evaporation, it’s a liquid that evaporates to form tiny droplets of water.

(b) Use your knowledge of changes of state and energy changes (energy in or energy out) to explain why this happens.

Well, it’s a process of different changes of state. Solids use energy to form a liquid, and then the energy uses the liquid to transfer it into a gas. That’s what kinds of process that’s used.

Figure 5.7. Writing sample for the chapter entitled “What are things made of?”

The answers to these questions read as follows. “Evaporation, it’s a liquid that evaporates to form tiny droplets of water.” and “Well it’s a process of different changes of state. Solids use energy to form a liquid, and the energy uses the liquid to transfer it into a gases. That’s what kinds of process that’s used.”

In the first part of his answer Sam recalled the name of the process of evaporation and gave some explanation of how the process happens. In the second part of the question he identified the three states of matter and demonstrated some understanding of the energy exchanges that are necessary for changes of state to occur. However, he did not limit his explanation to answering the question that was asked. That is, the specific energy exchanges that relate to the process of evaporation. When he had
completed this answer, Sam indicted that completing the concept maps had made it easier for him complete the written answer because it has helped him to recall the specific language that was required. When this sample is compared with those in Figures 5.5 and 5.6 it can be observed that it is more cleanly written and contains fewer indications of hesitancy.

5.3 Summary of Stage 2 of the Study

In Stage 2 of the study, Sam was assessed with the Working Memory Assessment Battery. The results of this assessment indicated that he had below average functioning of the phonological loop and average to above average functioning of the visuo-spatial sketchpad and central executive components of working memory.

In Trial 5, a scaffolding sequence that included the use of spoke word maps, spoke concept maps and responsive elaboration was tried and evaluated. While this sequence assisted Sam with the extraction of information from the text, it was felt that the removal of the step that required Sam to produce a written concept statement for each of the key concepts had a negative impact on Sam’s retention of the information contained in the text. The step that required Sam to complete written concept statements was re-introduced to Trial 6.

Despite the level of scaffolding provided in both Trials 5 and 6, Sam experienced considerable difficulty with the formulation of linking statements during the process of concept map construction. However, the evidence collected from the writing samples that were produced when Sam answered the extended recall conceptual questions suggests that the cumulative effect of the scaffolding sequence used in Trial
6 had a positive impact on the development of Sam’s conceptual understanding. The overall results of Stages 1 and 2 of the study are discussed in Chapter 6.
Discussion of the Implementation of the Scaffolded Concept-Mapping Process in Stage 1 and Stage 2 of the Study

The scaffolding activities used in Stage 1 and Stage 2 of the study had varying degrees of impact on the development of conceptual knowledge when James and Sam were required to use concept mapping to summarize a chapter of a science text. This impact was most evident at two stages in the concept-mapping process. The first was when the students were required to identify and represent their knowledge of the key concepts contained in the text, and the second was when the students were required to reconstruct and represent their knowledge to form a meaningful network of conceptual links on a concept map. The impact of the scaffolding activities on these two aspects of concept map construction is now discussed.

6.1 The Identification and Representation of Students’ Knowledge of Key Concepts

In order to assist with the identification and representation of James’s knowledge of the key concepts contained in the text, in Trial 1 and Trial 2 of Stage 1 of the study, three forms of predominately verbal scaffolding were provided. These were the provision of a list of key concepts, the completion of student-constructed concept statements and the use of responsive elaboration.

The use of the concept lists assisted James in locating the most important information contained in the chapter. However when James was required to represent this
information using a written concept statement, the statements that he produced were incomplete in terms of the number of sub-concepts that were identified and the information contained in the statements did not accurately represent the meaning of the concepts contained in the text. These findings are consistent with previous research that suggests that when extracting information from texts, students with learning difficulties experience difficulty with deciding what information they considered to be important, with what they should include in their summaries and with the transformation of the textbook information into gist (Winograd, 1984). These difficulties with information extraction are sometimes compounded by the fact that some features of science text, such as complexity of sentence structure, make science texts difficult to read (Fang, 2006). In addition to the difficulties that were encountered with finding and representing the meaning of the information contained in the text, the sentences that James used to convey this information contained a number of grammatical, syntactical and spelling errors. Also his handwriting was poorly formed and difficult to read.

The third form of scaffolding that was included in Trial 1 and Trial 2 of the study was the use of responsive elaboration to provide corrective feedback when James had completed each of the written concept statements. The statements that were produced during these trials required a large amount of corrective feedback from the researcher. James found this high level of interactive feedback both overwhelming and frustrating and as a result was not highly motivated to be involved in the correction process.

In summary, the combined use of predominately verbal scaffolding in the form of concept lists, student-constructed concept statements and the provision of corrective
feedback using responsive elaboration in Trial 1 and Trial 2 of the study failed to facilitate the extraction and representation of conceptual knowledge from the text.

In Trial 3 of Stage 1 of the study student-constructed spoke word maps were used to provide additional visuo-spatial scaffolding to aid the extraction and representation of conceptual knowledge. The computer program Inspiration 6 was used to construct the spoke word maps. In this trial, each spoke word map was constructed before James was required to complete the written concept statements. Corrective feedback using responsive elaboration was provided during the construction of the word maps. The inclusion of the student-constructed spoke word maps using Inspiration 6 had a positive impact on the identification and representation of conceptual knowledge in a number of ways.

Firstly, the visual presence of the spoke word map assisted with the extraction and representation of the key information from the text. Instead of having to store and rehearse the key conceptual knowledge in the phonological loop component of working memory, James simply looked at the map to check which information had already been found. The use of Inspiration 6 during this extraction process enabled him to make changes to the spoke word map very easily. When these additional visual scaffolds were used, the extraction and representation of information was less frustrating and James was a more willing participant in the process of map correction. Guthrie, Anderson, Aloa, and Rinehart (1999) suggest for reading instruction to be successful it must enhance the motivated use of strategies in new knowledge domains. The authors use the term reading engagement to describe the joint operation of motivations and strategies that occurs while students are involved in the construction
of conceptual knowledge during reading. One of the key benefits of the introduction of the spoke word maps using Inspiration 6 was that they greatly increased James’s desire to extract the information from the text and the effort that he was prepared to dedicate to the extraction process.

Secondly, the visual presence of the spoke word maps provided an ongoing point of reference during the use of the responsive elaboration when providing corrective feedback during the construction of the spoke word maps. The use of the visual template enabled the researcher to make James more aware of the current state of his word map and to encourage him to check if the information that had been included on the spoke structure was actually related to the concept at the centre of the map. In this way, James gradually refined the contents of the spoke word map. While James did not always initiate the process of map correction independently, he was more willing to participate in the process of self-correction. The use of this additional visual rehearsal technique seemed to enhance the processing of the textual information (McNeal & Dwyer, 1999; Nesbit & Adesope, 2006) and free attentional resources that could be used to monitor the ongoing processing demands of the task (Kalyuga et al., 1998).

Thirdly, the use of the spoke word maps provided an effective scaffold for the writing process and had a marked impact on the quality of the writing samples that were produced by James. The use of responsive elaboration in conjunction with the construction of the spoke word map almost eliminated the need for the provision of corrective feedback when the written statements were completed using the spoke maps. The quality of his hand writing became noticeably more legible, the concept
statements were more complete and the syntactic structure of the sentences that he used reflected an improved understanding of the conceptual information. If as Abell (2006) suggests, the purpose of writing in science classrooms is to build conceptual understanding through the use of clarity of expression, then the use of the spoke word maps as a scaffold for writing provided James with an opportunity to gain an experience of the writing process that resulted in the production of a sample of text that was more conceptually complete and more syntactically and grammatically correct.

When the spoke word maps were included in the scaffolding sequence there was an improvement not only in the extraction and recall of the conceptual knowledge contained in the text, but also this form of scaffolding facilitated the representation of this knowledge in written form. However, while the use of writing has been suggested as a means of fostering knowledge construction, of clarifying misconceptions and of encouraging students to reflect on their current level of understanding (Abell, 2006; Baker et al., 2008; Knipper & Duggan, 2006; Syh-Jong, 2007), the outcomes of this component of the current study suggest that for some students, the effectiveness of writing as a means of knowledge construction is dependent on how the writing activity is structured. This conclusion supports the suggestion made by Rowell (1997) that without appropriate scaffolding the promises of ‘writing to learn’ in science classrooms may not be fulfilled.

Lastly, the inclusion of the spoke word maps resulted in an improvement in James’s recall of the conceptual knowledge contained in the text. This finding supports research that suggests that the construction of graphic organizers aids the encoding of
information by facilitating the storage of a set of concept-related information as a single entity in long term memory (Marcus et al., 1996) and also that more structured sets of information are more easily retrieved from long-term memory (Chi & Koeske, 1983).

In addition to the provision of additional visuo-spatial scaffolding in the form of spoke word maps, in Trials 4, 5 and 6 of the study a step that required James and Sam to convert the spoke word maps to spoke concept maps was included. The discussion that occurred between the students and the researcher during this conversion process proved to be an effective means of further refining the students’ knowledge and understanding of the key concepts contained in the text. This finding supports research conducted by Bos and Anders (1990) that suggests that interactive vocabulary instructional techniques that focus on developing the relationships between concepts had the greatest impact on comprehension and vocabulary learning.

The combined use of the scaffolding sequence that included key concept lists, spoke word maps, spoke concept maps, written concept statements, mental modelling and responsive elaboration used in Trials 4 and 6 of the study had the greatest impact on the identification, representation and recall of the key concept-related information contained in the text. Specifically, the use of the spoke word maps aided the extraction and representation of the key conceptual knowledge from the text, while the conversion of the spoke word maps to spoke concept maps and the completion of the written concept statements aided by the use of mental modelling and responsive elaboration facilitated the restructuring of that knowledge. While this improved knowledge of key concepts provided the students with the language that enabled them
to participate more effectively in the discussion about the key concepts that occurred during the process of link construction, this level of scaffolding did not resolve the high level of difficulty that both James and Sam experienced with the linking of conceptual information to form the integrated structure of the concept map. In an attempt to facilitate this aspect of map construction, a number of additional scaffolding techniques were designed and evaluated.

6.2 The Linking of Conceptual Information to Form a Concept Map

Additional scaffolding techniques that were used to aid the process of link construction included the use of concept cards that could be physically manipulated by James while he was deciding which of the concepts could be linked (Novak et al., 1983), the conversion of spoke word maps to spoke concept maps (Bos & Anders, 1990) aided by the use of mental modelling and responsive elaboration to explicitly model the process of meaningful link construction (Duffy & Roehler, 1987; Duffy et al., 1988) and the use of partially-completed concept maps that provided a partial solution to the structure of the final concept map (Chang et al., 2002; Katayama & Robinson, 2000; Sweller et al., 1998) aided by the use of mental modelling and responsive elaboration to model and provide corrective feedback during the process of link construction (Duffy & Roehler, 1987; Duffy et al., 1988).

While the process of physical manipulation of the concept cards assisted James in deciding which of the concepts could be linked, it proved to be very time consuming and required a large amount of corrective feedback from the researcher. However it should be noted that the concept cards were only used in Trials 1 and 2 of the study. It was observed that the use of the concept cards was most effective when James had a
good knowledge of the key concepts. The use of this technique may have proved to be more effective if it had been used in Trials 4, 5 and 6 of the study when the conversion of spoke word maps to spoke concept maps had been used to provide James and Sam with a more refined knowledge of the key concepts.

In Trials 4, 5 and 6 of the study, the conversion of spoke word maps to spoke concept maps was used as a means of explicitly modelling the process of link construction. While the discussions that occurred between the students and the researcher during the conversion process could be used to make the students aware that a meaningful link had not been constructed, this awareness did not transfer to James’s and Sam’s monitoring and self-correction of meaningful link construction when James and Sam were required to develop new links on the partially-completed concept maps. The students did not self-correct independently and needed to be constantly reminded to check if the links that they had constructed represented the meaning of the information contained in the text. The main benefit associated with the conversion of spoke word maps to spoke concept maps was related to the clarification of students’ conceptual knowledge which in turn facilitated the language interactions that occurred between the students and the researcher during the process of link construction.

The use of the partially-completed concept maps eliminated the need for James and Sam to decide which of the concepts could be directly related and as a result reduced some of the cognitive load associated with the complex task of link construction (Sweller et al., 1998). However, it also reduced some of the encoding benefits that were associated with allowing them to be more engaged in the process of deciding which of the concepts could be linked, as was the case when James had the
opportunity of using the concept cards. The importance of the encoding benefits that result when there is a high level of student engagement in the process summarization using partial graphic organizers has also been noted by Katayama and Robinson (2000).

Because of the level of difficulty that James and Sam experienced with link construction, it may seem that it would have been more expedient to provide the students with the links rather than involving them in the high level of language interaction that was required for the development of meaningful links. While the dilemma created by the need to encourage depth of processing in situations where there is high cognitive load during the scaffolding of the concept-mapping process has been acknowledged by Chang et al. (2002), the use of scaffolding techniques such as map correction (Chang et al., 2002) and collaborative concept mapping (Van Boxtel et al., 2002), which involved study participants in high levels of verbal evaluative processing of conceptual information, have been shown to have the greatest impact on the development of understanding. These findings are also supported by Klein (2006) and Yore and Treagust (2006) who emphasise the role of language in the development of science understanding.

In the current study, both James and Sam experienced marked difficulty with the process of link formulation. The scaffolding sequence that proved to be most effective and time efficient in facilitating the development of conceptual understanding represented through the process of link formulation used a combination of verbal and visuo-spatial scaffolding activities. These included the use of spoke word maps, spoke concept maps, written concept statements, partially-completed concept maps, mental
modelling, responsive elaboration and Inspiration 6. During the use of this combination of scaffolding activities a number of benefits that facilitated the processing of the conceptual knowledge during the process of link construction were identified.

The first of these benefits was related to the reprocessing of textural information that resulted from the interactive dialogue between the student and the researcher during link construction. This dialogue provided an opportunity for the further elaboration and clarification of the students’ understanding of the information contained in the text and for the identification and clarification of students’ misconceptions. The usefulness of concept maps as a tool to identify student misconceptions is supported by Van Zele et al. (2004). Barker and Millar (1999) suggest that explicit teaching may have a role in resolving the misconceptions that students hold about science concepts, while Sungur, Tekkaya, & Geban (2001) identify the specific role of intensive teacher-student dialogue in the clarification of students’ misconceptions in science. In the current study the visual presence of the map provided a focus for the communication that occurred between the students and the researcher (Kinchin et al., 2000). Also, the use of responsive elaboration during the process of link construction provided an opportunity to model language structures. Sam’s observation that “doing the maps helps to produce the language that is needed when you are writing the sentences” supports the findings of a study conducted by Mercer, Dawes, Wegerif, and Sams (2004) that students can be assisted to develop the use of spoken language as a tool to develop their understanding in science and the suggestion made by Brice (2004) that the use of written language is linked to prior knowledge of a range of
foundation oral and written language skills such as spelling, vocabulary, sequential order and sentence structure.

The second of the benefits that was associated with the combined use of verbal and visuo-spatial scaffolding related to the fact that during the interactions that occurred between both James and Sam and the researcher during the completion of the spoke concept maps and the partially-completed concept maps, neither of these students seemed to be aware when a meaningful link had been constructed. While the combined use of the visual template of the map, responsive elaboration and the flexibility provided by the use of Inspiration 6 did not enable the students to monitor their learning independently, the visual presence of the partly-completed maps allowed the student to propose a link on the map that could be evaluated with the assistance of feedback from the researcher. The value of the use of the interactive dialogue was that it could be used to draw the students to a point where they could recognize when meaningful relationship between the two concepts had been reached. This process of link reformulation using mental modelling and responsive elaboration sometimes resulted in an “ah-ha” moment (Fensham et al., 1981) when the students came to the realisation of a sudden change in their level of conceptual understanding. In this situation the structure of the map provided a visual focus for the interactions that occurred between the students and the researcher. The benefit of concept maps in providing students with a means of visualizing learning materials and providing a focus for reflection has been noted by Kinchin et al., (2000)

This finding is consistent with previous research that suggests that students who experience difficulty with learning do not spontaneously monitor and regulate their
learning and activate comprehension monitoring strategies only when they have been cued to do so (Bos & Filip, 1984), and are less likely to evaluate whether new information makes sense relative to their background knowledge (Owings et al., 1980). Yore and Treagust (2006) suggest that students need to monitor and evaluate their own thinking to be able to recognise when any change in their understanding of science concepts has occurred.

The instructional sequence that cumulatively contributed to the development of the students’ conceptual knowledge during the scaffolding of the concept-mapping process in Stage 1 and Stage 2 of the study included an initial component that aided the extraction and representation of information from the text using key concept lists, spoke word maps, spoke concept maps, written concept statements, Inspiration 6 and responsive elaboration, and a second component that facilitated the process of link construction using partially-completed concept maps, mental modelling and responsive elaboration.

While the use of this scaffolding sequence did not provide an immediate benefit for the process of link construction during the construction of the concept maps, when writing samples taken at the end of a science chapter where no scaffolding intervention had been provided, were compared with answers to the extended recall conceptual questions taken after the scaffolded concept-mapping process had been implemented, differences in the representation of conceptual understanding were evident. Also, when Sam had provided answers, from memory, to some of the extended recall conceptual questions, he commented that “doing the maps helps to produce the language that is needed when you are writing the sentences”.
In Stages 1 and 2 of the study James and Sam experienced considerable difficulty with the formulation of linking statements on the concept maps. In order to formulate a linking statement, the students needed to store conceptual information relating to both concepts in working memory while at the same time evaluating whether or not a meaningful link had been constructed. While in the current study, it is suggested that the functioning of the student’s working memory would have a considerable impact on a student’s ability to carry out this operation it could also be argued that the availability of the student’s language knowledge may also impact on the student’s formulation of linking statements. At the end of Stage 2 of the study it was decided to investigate some aspects of each student’s general language ability.

6.3 General Language Assessment for James and Sam

To assess the students’ general language ability two assessment instruments were used. These were the Peabody Picture Vocabulary Test Third Edition (PPVT 111) (Dunn & Dunn, 1997) and the Clinical Evaluation of Language Fundamentals Screening Test – Fourth Edition (CELFST-4) (Semel et al., 2004). The overall assessment results for each student are shown in Table 6.1.
Table 6.1

*Summary of Language Assessment*

<table>
<thead>
<tr>
<th>Name of Test</th>
<th>Student’s Name</th>
<th>Test Score</th>
<th>Test Score</th>
<th>Test Score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Standard score</td>
<td>Criterion score</td>
<td>Descriptor</td>
</tr>
<tr>
<td>PPVT 111</td>
<td>James</td>
<td>114</td>
<td>96</td>
<td>high average, low average</td>
</tr>
<tr>
<td></td>
<td>Sam</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CELFST-4</td>
<td>James</td>
<td>24</td>
<td>22</td>
<td>low average, low average</td>
</tr>
<tr>
<td></td>
<td>Sam</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

While each student’s results on the PPTV 111 varied considerably, the test scores fell within the average range. Also, the Criterion Score obtained by each student on the CELFST-4 did not fall below the point where further language assessment would be recommended. However, when the assessment results for each of the subtests on the CELFST-4 were considered individually, it was possible to identify one subtest, *Sentence Assembly* that both students had found particularly difficult. These results are presented in Table 6.2.
Table 6.2

Summary of Test Scores for the CELFST-4

<table>
<thead>
<tr>
<th>Name of Sub-test</th>
<th>Student’s Name</th>
<th>Test Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Following Directions</td>
<td>James</td>
<td>6/6</td>
</tr>
<tr>
<td></td>
<td>Sam</td>
<td>4/6</td>
</tr>
<tr>
<td>Recalling Sentences</td>
<td>James</td>
<td>9/9</td>
</tr>
<tr>
<td></td>
<td>Sam</td>
<td>7/9</td>
</tr>
<tr>
<td>Sentence Assembly</td>
<td>James</td>
<td>1/6</td>
</tr>
<tr>
<td></td>
<td>Sam</td>
<td>2/6</td>
</tr>
<tr>
<td>Semantic Relationships</td>
<td>James</td>
<td>4/6</td>
</tr>
<tr>
<td></td>
<td>Sam</td>
<td>6/6</td>
</tr>
<tr>
<td>Word Classes</td>
<td>James</td>
<td>4/7</td>
</tr>
<tr>
<td></td>
<td>Sam</td>
<td>4/7</td>
</tr>
</tbody>
</table>

In the *Sentence Assembly* subtest the students were presented with a series of sentences in jumbled written form, for example, “In the house the dog is” and asked to reorganise the sentence in two ways that make sense. This reorganisation was to be done in memory. Both students experienced considerable difficulty with the majority of these items. James answered only one item out of six correctly, while Sam correctly answered two out of six. Instead of reorganising one item to “We shouldn’t park the car here” James gave his answer as “We here the car shouldn’t park”. Similarly, Sam gave one of his answers as “The teacher isn’t to give the test planning” instead of saying “The teacher isn’t planning to give the test”. While they were attempting the test items both students regularly asked “Does that make sense?”

The results from the *Sentence Assembly* assessment suggest that despite the familiarity and lack of complexity of the language, both James and Sam experienced considerable difficulty when they were attempting to decide whether or not the
different combinations of verbal information made sense. However, when the elements of the sentences were written onto cards that could be physically manipulated by the students, both James and Sam constructed a meaningful sentence very quickly. These results provide support for the view that limitations in the functioning of the students’ verbal working memory and not the students’ general language knowledge are a prime cause of the difficulty these students were experiencing with the extraction of complex information from the text and with the formulation of meaningful links on the concept map.

The observational information and work samples collected in Stage 1 and Stage 2 of the current study suggest a number of similarities between the difficulties experienced by both James and Sam. Firstly, both students were found to difficulties with the functioning of the phonological loop component of their working memory system. Each of these students benefited from the combined use of verbal and visuo-spatial scaffolding when they were required to extract key concept-related information from the text. Secondly, both James and Sam had experienced considerable difficulty with the formulation of meaningful linking statements during the process of concept map construction. Evidence collected from the written answers to the extended recall conceptual questions suggests that the use of the multi-component instructional sequence that included the use of both verbal and visuo-spatial scaffolding techniques had a positive impact on both students’ representation of conceptual understanding of the information contained in the science text.

When students attend Learning Support they often work with teacher aides who are working under the supervision of a Learning Support Teacher on coursework-related
tasks. If the scaffolded concept-mapping process is to be used effectively in the student’s learning support sessions to assist science learning, it is essential that the teacher aides are able to implement the process at a relatively independent level. In Stage 3 of the study, scaffolded concept mapping was implemented using teacher aide assistance. Details of the implementation of the scaffolded concept-mapping process using teacher aide assistance are outlined in Chapter 7.
CHAPTER 7

Stage 3: Implementing Scaffolded Concept-Mapping Using Teacher Aide Assistance

Research in the area of literacy education suggests that teacher aides can be used effectively to implement scaffolded reading programs (Axford, 2007; Woolley & Hay, 2007). The aim of Stage 3 of this study was to investigate whether teacher aides could be used to implement the scaffolded concept-mapping process with students who were experiencing difficulty with science learning. Stage 3 of the study was conducted in three parts. Firstly a third student, Tim, was assessed using the Working Memory Assessment Battery. Secondly, a teacher aide working under the supervision of the researcher implemented the scaffolded concept-mapping process developed in Trial 4 of Stage 1 of the study with Tim. This trial is referred to as Trial 7. Lastly, the scaffolded concept-mapping process developed in Trial 4 of Stage 1 of the study was implemented by a group of four teacher aides while they were working with learning support students under the supervision of the researcher in the Learning Support Centre. This trial is referred to as Trial 8.

7.1 The Development of Tim’s Working Memory Profile

Tim was assessed with the Working Memory Assessment Battery that aimed to measure the functioning of the phonological loop, visuo-spatial sketchpad and central executive components of his working memory.
7.1.1 Tim’s Working Memory Assessment Summary

The assessment of working memory functioning identified a number of individual differences in Tim’s working memory profile. The results of this assessment are shown in Table 7.1.

<table>
<thead>
<tr>
<th>Component of Working Memory</th>
<th>Name of Test</th>
<th>Level of Functioning Scaled Score</th>
<th>Level of Functioning Descriptor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phonological Loop</td>
<td>Digits Forward</td>
<td>6</td>
<td>Below Average</td>
</tr>
<tr>
<td>Phonological Loop</td>
<td>Auditory Word Memory</td>
<td>7</td>
<td>Below Average</td>
</tr>
<tr>
<td>Visuo-spatial Sketchpad</td>
<td>Visual Sequential Memory</td>
<td>13</td>
<td>High Average</td>
</tr>
<tr>
<td>Visuo-spatial Sketchpad</td>
<td>Abstract Visual Memory</td>
<td>10</td>
<td>Average</td>
</tr>
<tr>
<td>Visuo-spatial Sketchpad</td>
<td>Memory for Location</td>
<td>3</td>
<td>Below Average</td>
</tr>
<tr>
<td>Central Executive</td>
<td>Semantic Organisation</td>
<td>8</td>
<td>Low Average</td>
</tr>
<tr>
<td>Central Executive</td>
<td>Visual Matrix</td>
<td>8</td>
<td>Low Average</td>
</tr>
</tbody>
</table>

Tim’s working memory profile indicates that all measures of the functioning of the phonological loop component of the working memory fell in the below average range. Two out of the three measures of the functioning of the visuo-spatial sketchpad fell in the average to high average range with one, Memory for Location, falling on a below average score. While both measures of central executive functioning fell in the average range, both were at the lower end of the range. In general Tim’s working memory profile fits Pattern 1; that is, below average functioning of the phonological loop, and average functioning of the visuo-spatial sketchpad and central executive. However, unlike the working memory profiles for James and Sam in Stages 1 and 2 of
the study, there is greater variation within this pattern. Firstly Memory for Location, a
notable feature of the concept-mapping process, fell in the below average range and
secondly the two measures central executive functioning fell at the lower end of the
average range.

7.2 The Implementation of Scaffolded Concept-Mapping with Tim using
Teacher Aide Assistance

7.2.1 Design of Trial 7
In Trial 7 the scaffolded concept-mapping process that has been used in Trial 4 of
Stage 1 of the study was implemented with Tim by a teacher aide, referred to as Sue,
who was working under the supervision of the researcher. Prior to the implementation
of this trial, Tim had received two hours of instruction on the construction of word
and concept maps using Inspiration 6. This trial was conducted using a science
chapter entitled “What are things made of?”

7.2.2 Implementation of Trial 7
Trial 7 was conducted over a period of 12 one-hour learning support sessions. Sue
was provided with an instructional sequence that was to be followed during the
implementation of the scaffolded concept-mapping process. This was:

1. Provide the student with a list of key concepts for the chapter.
2. Ask the student to read the text and to develop a spoke word map for each of the
   concepts in the subset using Inspiration 6.
3. When the word maps for each of the concepts in the subset have been completed ask the student to convert the word maps into spoke concept maps using Inspiration 6.
4. Using these concept maps ask the student to complete the written concept statements for each of the concepts contained in the subset.
5. Give the student the template for the partially-completed concept map and ask him to draw up the completed map using Inspiration 6.
6. When the concept map has been completed, check and clarify any misconceptions.
7. Save and copy this map into the student’s file.
8. Repeat this process with the next set of concepts.
9. When the next partially-completed concept map has been completed add it to that portion of the total map that has already been constructed.
10. Repeat this process until all concept sets have been completed and the total concept map for the chapter has been completed.
11. Ask the student to complete the written answers to the extended recall conceptual questions independently.

7.2.3 Evaluation of Trial 7

7.2.3.1 Evaluation of Tim’s performance on the scaffolded concept-mapping task

The evaluation of Tim’s performance during the concept-mapping process is based on the observations recorded by the teacher aide while working with Tim and on observations made by the researcher when supervising the teacher aide’s implementation of the scaffolded concept-mapping process.
Despite having received a considerable amount of prior instruction in the use of Inspiration 6, when Tim was required to perform the joint operations of the extraction of information from the text and the representation of this information on a spoke word map using the first concept subset, he required a considerable amount teacher aide assistance to identify all of the key information in the text and in using the computer program to construct and link the information bubbles on the spoke word map. Even when he mastered the use of the program in one session, he had forgotten how to use the program by the next session. As a result of these difficulties Tim took approximately two sessions to complete the tasks – twice as long as it had taken Sam in Stage 2.

In addition to the amount of time that Tim required to construct the spoke word maps, when he was required to convert them to spoke concept maps, he had forgotten what some of his spoke word maps meant. While the need to revise the information in some of the spoke word provided an opportunity for the additional elaboration of the concept related information, it would have been a more efficient use of the time available if Tim had converted the word maps to concept maps after each concept had been completed.

When Tim completed the written concept statements using his spoke concept maps, the concept statements contained all of the key concept-related information and required very little corrective feedback from the teacher aide. However, when he was required to complete the partially-completed concept maps, Tim did not formulate the linking statements independently and required a considerable degree of modelling and corrective feedback from the teacher aide.
7.2.3.2 Evaluation of teacher aide assisted scaffolded concept mapping

In order to evaluate the use of teacher aide assistance to support the delivery of the scaffolded concept-mapping process, the researcher observed the teacher aide while she worked with Tim and met with her at the end of each session to discuss how each session had progressed. During these discussions, two main difficulties associated with the use of teacher aide assistance were identified. The first of these was the need for regular detailed communication between the teacher aide and the researcher in order to monitor and respond to the student’s current level of performance, and the second was the difficulty encountered by the teacher aide in providing ongoing corrective feedback to Tim in relation to the accuracy of his developing scientific understanding. In response to these difficulties a number of intervention aides were developed for use in Trial 8.

7.3 The Re-evaluation of the Use of Teacher Aides to Implement Scaffolded Concept Mapping

7.3.1 Design of Trial 8

During Trial 8 the scaffolded concept-mapping process that had been used in Trial 4 of Stage 1 of the study was implemented by four teacher aides who were working under the supervision of the researcher. The students who worked with the teacher aides were in Year 9 and had been referred to Learning Support because of difficulties they were experiencing with reading comprehension. These difficulties were evident
in the area of science learning particularly when the students were required to express their understanding of science concepts in written form.

In order to enable the teacher aides to provide more effective feedback to the students on the current state of their scientific knowledge and to provide a framework for more effective communication between the teacher aides and the researcher in Trial 8 of the study, a chapter related Science Curriculum Booklet and a Teacher Aide Checklist were developed. In addition, the teacher aides participated in a series of eight training sessions that were aimed at improving their understanding of the learning process.

7.3.1.1 Chapter related Science Curriculum Booklet

The Curriculum Booklet used in Trial 8 was developed for the text chapter “Living with acids and bases”. This booklet provided the teacher aides with copies of:

1. A set of instructions for the implementation of the concept-mapping process
2. The key concept word list divided into concept subsets.
3. Individual key concept word maps for each concept subset.
4. A template for student-constructed written concept statements for the key concepts in each concept subset.
5. A template for the partially-completed concept maps for each concept subset
6. A completed whole-chapter concept map.
7. A template for the extended recall conceptual questions.

The set of instructions for the implementation of the scaffolded concept mapping process by the teacher aides is outlined in Section 7.3.2. Samples of curriculum materials 2 -7 are contained in the Appendix.
**7.3.1.2 Teacher Aide Training**

Within the Learning Support Department teacher aide training is provided by the researcher on an ongoing basis through regular weekly one-hour teacher aide meetings. This set of 8 training sessions covered topics relating to:

1. The operation of the human memory system and how it can be influenced by stress and motivational factors (Borkowski et al., 1988; Bourne et al., 1979).
2. Cognitive load, its relationship to the functioning of working memory and its impact on the effectiveness of instruction (Kalyuga et al., 1998).
4. Comprehension and the importance of prior knowledge in the development of understanding (Anderson, 1986).
5. The use of learning strategies and the general principles of strategy instruction. Specific information relating to the use of responsive elaboration, mental modelling, word maps and concept mapping was also provided (Duffy & Roehler, 1987; Duffy et al., 1988; Novak & Canas, 2006; Pressley et al., 1987; Roehler & Duffy, 1986).

These training sessions provided the teacher aides with an opportunity to discuss the material that had been presented by the researcher, and how the information related to their daily interactions with students during the implementation of the scaffolded concept-mapping process.
7.3.1.3 Teacher Aide Checklist

The Teacher Aide Checklist divided the scaffolded concept-mapping process into four main areas. These were Word Map, Concept Map Conversion, Writing Sentences and Concept Map Completion. Teacher aides were asked to complete the checklist by referring to a number of questions that specifically related to each component of the concept-mapping process. Details of these questions are contained in Table 7.2.

Table 7.2
Teacher Aide Checklist

<table>
<thead>
<tr>
<th>Area of Teacher Aide Checklist</th>
<th>Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spoke Word Map</td>
<td>Extracting information from the text – How much assistance was required? Did the student check the meaning of the information? Did the student self-question? Was the spelling correct? Was the student focussed? Was the student interested?</td>
</tr>
<tr>
<td>Spoke Word Map/ Concept Map Conversion</td>
<td>Availability of language for the connector words? Did the links construct meaning? Did the student self check and evaluate meaning? Did construction of the linking words “force” elaboration/construction of meaning?</td>
</tr>
<tr>
<td>Writing Sentences</td>
<td>Was the information complete – did it contain key points Did the student self-correct written statements? Was the student focussed? Was the student interested?</td>
</tr>
<tr>
<td>Concept Map Completion</td>
<td>Was the student able to recall appropriate linking statements? Did the student self-check? Level of cognitive demand? Level of engagement? Depth of processing?</td>
</tr>
</tbody>
</table>
The teacher aides who participated in Trial 8 had participated in the teacher aide training sessions and in addition, had been given training on how to use the Teacher Aide Checklist and the Science Curriculum Booklet.

7.3.2 Implementation of Trial 8

Trial 8 was conducted over a series of 12 one-hour learning support sessions. Due to time limitations and the fact that some of students who participated in the trial needed to work on areas of their coursework other than science, not all students completed the whole of the scaffolded concept-mapping process for each chapter. However most of the students completed enough of the scaffolded concept-mapping process for teacher aides to be able to comment on its effectiveness.

The teacher aides were provided with a sequence of steps that were to be followed during the implementation of the scaffolded concept-mapping process. These were:

1. Provide the students with a list of key concepts for the chapter.
2. Ask the students to read the text and to develop a spoke structured word map for each of the concepts in the subset, using Inspiration 6.
3. Check each of the word maps using the reference sheet.
4. Complete the Word Map section of the Teacher Aide Checklist.
5. When the word maps for each of the concepts in the subset have been completed ask the students to convert their word maps into spoke structured concept maps using Inspiration 6.
6. Complete the Concept Map Conversion section of the Teacher Aide Checklist.
7. Using these concept maps ask the students to complete the written concept statements for each of the concepts contained in the subset.

8. Complete the Writing Sentences section of the Teacher Aide checklist.

9. Give the students the template for the partially-completed concept map and ask them to draw up the completed map using Inspiration 6.

10. Check and clarify any misconceptions when the concept map has been completed.

11. Save and copy this map into the student’s file.

12. Complete the Concept Map Completion section of the Teacher Aide Checklist.

13. Ask the students to complete written answers to the conceptual questions. Ask the students to complete written answers to the conceptual questions independently.

14. Repeat this process with the next set of concepts.

15. When the next partially-completed concept map has been completed add it to that portion of the total map that has already been constructed.

16. Repeat this process until all concept sets have been completed and the concept map for the whole chapter has been completed.

When the teacher aides had implemented the concept-mapping sequence outlined in Trial 8 they were asked to provide written answers to a number of reflective questions. The first set of questions required the teacher aides to record their self-perceptions of the usefulness of the Science Curriculum Booklet and the Teacher Aide Checklist. A summary of the questions that were used and some of the teacher aides’ direct responses to these questions is included in Table 7.3.
The second question asked the teacher aides to reflect on the students’ use of the concept-mapping process and to record their self-perceptions of the students’ use of the scaffolded concept-mapping process. The teacher aides were asked to “Comment on the use of the scaffolded concept-mapping process with students from a teacher aide perspective.” A summary of some of the teacher aide direct responses is shown in Table 7.4.
Table 7.4

Teacher Aide Responses for the Use of the Scaffolded Concept-Mapping Process

Teacher Aide Responses

Definitely a more attractive prospect for students as they all like to use the computer. Students were actually enthusiastic. Had many opportunities to do coursework and assignment tasks for other subjects but they chose to do Science. Would walk in and jump straight on computers.

Students felt a lot more successful with this task – able to see at a glance what each concept was about once word/concept maps were completed. All asked for copies so they could be used as study aides. A few mentioned they liked the visual aspect of concept maps – easier than reading textbook.

Students were initially very reluctant to work on science definitions. However their reluctance usually eased when they were told and understood the full process- by showing them our completed folders (very helpful) and that they would be using a computer.

Many were distracted from the task by fiddling with graphics. Had to be reminded to concentrate on the task at hand.

Most need help/prompting to identify key points from the text. Many gave “examples” instead of “definitions”.

Student initially very reluctant to write. After the first two words his confidence grew and started to complete the word map independently. Once word map completed struggled to add connecting words. After reading them back to him he then realised it did not make sense but he couldn’t find other useful words to give a better meaning. When he then began to write up the sentences he was able to give good meaning to the words in well constructed sentences. It was like the light bulb came on as he actually said “Oh, I understand this now”. With this confidence he was focussed and keen to get it finished.

Difficulty writing. ID found using his concept maps as a guide to write a great help to guide him.

There have been several students in Year 9 whom I have watched come to the realization that they actually understand a scientific concept after having created a word/concept map.

I struggled because I felt that students did not self check or self question unless I asked them.

Did the student self check? Say it aloud, then me saying it again, the making him say it again. He would go into a deeper thinking process to hear it said, to see if it constructed meaning.
7.3.3 Evaluation of Trial 8

In order to evaluate the use of teacher aide assistance to implement the scaffolded concept-mapping process in Trial 8 of the study, the researcher observed the teacher aides while they worked with the students and met with the teacher aides to discuss their perceptions of the implementation process. Overall, the teacher aides worked effectively with the students to enable them to develop a concept map for specific text chapters. As was the case in Trial 7, the greatest difficulty associated with teacher aide implementation of the concept mapping process was the difficulty encountered by the teacher aides in providing accurate corrective feedback to the students. The accuracy of this feedback improved as the teacher aides became more familiar with the content of each chapter. An evaluation of specific aspects of the implementation process is now discussed.

7.3.3.1 Evaluation of the teacher aide training

The teacher aide training provided the teacher aides with a working knowledge and understanding of the learning process and the terminology that allowed them to communicate information about the students’ learning needs and current level of performance to the researcher. The training was also necessary for the successful completion of the checklist.

The weekly one-hour teacher aide training sessions also provided an opportunity for any clarification that was required with the ongoing implementation of the concept-mapping process and for whole-group feedback sessions where teacher aides could raise any concerns or questions about their understanding of the concept-mapping process and the difficulties that students were experiencing.
7.3.3.2 Evaluation of the Science Curriculum Booklet

The use of the Science Curriculum Booklet gave the teacher aides a greater degree of independence when they were working with the students. They were also more confident that they could provide students with the correct feedback information. The comments made by the teacher aids such as “to have a hard copy in front of us helps us to make sure the student is on the right track” and “the booklet helped me to structure my understanding” support these suggestions. The teacher aide comments are contained in Table 7.4.

7.3.3.3 Evaluation of the Teacher Aide Checklist

The use of the Teacher Aide Checklist enabled the teacher aides to evaluate specific aspects of the students’ performance on each part of the concept-mapping process and to reflect on the kinds of difficulties that students were experiencing with the concept-mapping task. Once they became more aware of these difficulties they began to reflect on how they could change their teaching practice to improve student performance. The comments made by the teacher aides such as “having the checklist has prompted me to be more aware of each student’s performance” and “the checklist also helped me to realize the depth of processing the students need” support these conclusions. The teacher aide observations are provided in Table 7.4. The use of the checklist also made the process of providing feedback to the researcher on the performance of each student less time consuming.

No formal evaluation of students’ concept maps was conducted by the researcher in Trials 7 and 8 of the study. However, teacher aides were asked to record their self-
perceptions of the use of the scaffolded concept-mapping process with the students. These self-perceptions are provided in Table 7.4.

7.3.3.4 Teacher aide evaluation of the scaffolded concept-mapping process

The teacher aide evaluation of the scaffolded concept-mapping process reinforced previous observations made by the researcher that relate to the effectiveness of the intervention. Comments such as “students were actually enthusiastic”, “students felt a lot more successful with this task” reflect the impact of the use of Inspiration 6 on the students’ level engagement and motivation. The positive impact on the writing process is reflected in comments such as “Difficulty writing. ID found using his concept maps as a guide to write a great guide to him”. The impact of the use of spoke word maps and concept maps on the development of conceptual understanding is reflected in comments such as “several students in Year 9 whom I have watched come to the realisation that they actually understand a scientific concept after having created a word/concept map”. Comments such as “I struggled because I felt that students did not self check or self question unless I asked them” highlighted the degree of scaffolding students required with the processes of self-correction and meaning construction. The teacher aide comments are contained in Table 7.4.

In general, the implementation of the scaffolded concept-mapping process using teacher aide assistance proved to be an effective means of providing the high level of support that was required by the students. The development of the curriculum materials was essential for the successful implementation of scaffolded concept-mapping process. The observational information recorded by the researcher and teacher aide feedback collected during the study supports previous research that suggests that for tutor assisted reading programs to be effective there needs to be a
high level of tutor scaffolding and monitoring of students’ reading skills and high levels of ongoing tutor training and supervision (Woolley & Hay, 2007). A clear, explicit instructional framework is also required (Axford, 2007). In addition, for the teaching of science concepts to be effective teachers require a high level of science knowledge (Abd-El-Khalick & BouJaoude, 1997).
CHAPTER 8

Discussion of the Findings of the Study

The current study investigated the impact of a number of scaffolding techniques on the development of conceptual knowledge when students who were experiencing difficulty with science learning used concept mapping to summarise a chapter of a science text. The study sought to establish the extent to which students who experience difficulty with science learning have working memory profiles that identify individual differences in working memory functioning, and how these individual differences in the functioning of working memory might impact on the type of scaffolding that was required. The scaffolded concept mapping process was also implemented using teacher aide assistance. Design-based research was selected as the methodology for the current study as it aims, through the investigation of cognition in context, to impact directly on practice while at the same time generating evidence-based claims about learning that would be of value to others (Barab & Squire, 2004).

This chapter begins with an evaluation of the impact of the scaffolded concept-mapping process on the development of conceptual knowledge for two of the students, James and Sam, who participated in the current study. It continues with a discussion of the nature of the individual differences in working memory functioning that were identified for the three students, James, Sam and Tim, who were assessed using the Working Memory Assessment Battery during the study, and with a consideration of how these individual differences in working memory functioning might be used to explain the observed changes in conceptual knowledge development.
that occurred during the use of the scaffolded concept-mapping process. It concludes
with a consideration of the implications of the findings of the study for classroom
teaching practice.

8.1 The Impact of Scaffolded Concept Mapping on the Development of
Conceptual Knowledge

While it has been suggested that the use of a concept mapping strategy provides a
scaffold that facilitates knowledge construction (Novak & Canas, 2006), James and
Sam benefited from the use of a number of additional scaffolding techniques to aid
the development of conceptual knowledge when they used concept mapping to
summarise a chapter of a science text. Specifically, the instructional approach that
was developed during the study identified a sequence of scaffolding techniques that
facilitated two aspects of conceptual knowledge development that occurred during the
concept-mapping process. The first of these was the extraction, representation and
recall of the key conceptual knowledge contained in the text, and the second was the
formulation of meaningful propositions that represented the students’ understanding
of the relationships between the concepts represented on the whole-chapter concept
map.

The high level of conceptual complexity associated with the learning of new science
concepts from science texts is a significant factor that influences the teaching of new
scientific knowledge (Fang, 2006). The specific scaffolding sequence that was found
to be most effective in facilitating the students’ extraction, representation and recall of
the conceptual information contained in the textbook chapters used in this study
included the use of a list of key concepts, the construction of spoke word maps and spoke concept maps supported by the use of Inspiration 6, responsive elaboration and mental modelling and the completion of written concept statements with corrective feedback provided through the use of responsive elaboration. The effectiveness of the use of this scaffolding sequence is supported by the observations made during Trials 1-6 of the study.

In Trial 1, the first scaffolding sequence that was tried involved the use of concept lists, written concept statements and responsive elaboration. Instead of facilitating the development of concept knowledge, when these predominately verbal scaffolding activities were used, James experienced considerable difficulty with the extraction, representation and recall of the key concept-related information from the text. During this trial James found the corrective feedback provided by the researcher overwhelming and became disengaged and frustrated with the extraction and representation process. These observations are outlined in section 4.2.3.

The inclusion of the student-constructed spoke word maps in the scaffolding sequence that was used in Trial 3 of Stage 1 of the study had a marked impact on the extraction, representation and retention of conceptual information from the text. In contrast to the scaffolding sequence that had required James to represent the key conceptual information directly into a written concept statement, the inclusion of the spoke word maps allowed James to represent the key conceptual knowledge in a simplified, visual, diagrammatic form. The visual presence of the word map enhanced the effectiveness of the verbal interactions between James and the researcher. During these exchanges, James was more likely to refer to the structure of the map and check
if he had included all of the key information contained in the text. The use of Inspiration 6 made it easier for James to make the necessary changes to his word maps when the researcher provided corrective feedback using responsive elaboration. These observations are outlined in section 4.2.9.

In Trial 4 of the study, a step that required the conversion of spoke word maps to spoke concept maps was included in the scaffolding sequence. The inclusion of this step provided the researcher with further opportunities to clarify and refine James’s knowledge and understanding of the key concepts contained in the text. Also, the development of the spoke word maps and concept maps before the completion of the written concept statements, improved the effectiveness of the use of writing activities as a means of providing an opportunity for the further elaboration and rehearsal of the textual information. The construction and refining of the spoke word maps and spoke concept maps in combination with the completion of the written concept statements improved James’s recall of the key conceptual knowledge in the text. These observations are outlined in section 4.2.12.

The use of the scaffolding sequence that included the use of key concept lists, spoke word maps, spoke concept maps and written concept statements supported by the use of Inspiration 6, responsive elaboration and mental modelling was found to be an effective means of developing the students’ knowledge of key concept for both James and Sam. As these students became more familiar with the use of this sequence of scaffolding activities they required less supervision and feedback from the researcher. The students approached the task of information extraction enthusiastically and for a large part of the time more independently. In addition, the students were more likely
to engage in the writing process and this process of writing fostered a greater understanding of the conceptual knowledge. The exception to this was when Sam was required to process particularly conceptually complex text passages. In this case, greater use of responsive elaboration was required. These observations are outlined in sections 5.2.6.

While the use of this scaffolding sequence enabled the students to extract and represent the key concept-related information from the text and to clarify their vocabulary knowledge so that the concepts contained in the chapters could be discussed and recalled more effectively, this improvement in the availability of domain-specific knowledge did not have a marked impact on the difficulties associated with the actual process of meaningful link formulation.

To construct a meaningful proposition using the concepts from the concept list, James and Sam needed to decide which of the concepts could be related and then to formulate a meaningful link that represented their understanding of the relationship between the two concepts. In order to improve the process of deciding which concepts could be related and with the formulation of meaningful propositions on the map, three scaffolding techniques were tried and evaluated. The first of these involved the use of concept cards that could be physically manipulated during the process of link formulation (Novak et al., 1983; White & Gunstone, 1992). This provided the students with a visual means of flexibly representing the concepts. The second involved the explicit teaching of the process of link construction through the use of mental modelling when the spoke word maps were converted to spoke concept maps (Bos & Anders, 1990). This process was used to improve the students’ metacognitive
knowledge of the process of link construction. The third involved the use of partially-completed concept maps (Chang et al., 2002). These maps were used to assist students with the visual positioning of concepts and to reduce the cognitive load associated with the process of meaningful link construction. These scaffolding activities were used in conjunction with responsive elaboration and Inspiration 6.

The use of the concept cards provided a means of physically moving the concepts around while the overall structure of the map was being developed. This map structure was then transferred to the computer using Inspiration 6 where conceptual links were added and final adjustments to the map were made. The process of selecting two concepts and then working out, in conjunction with the researcher, whether or not a meaningful link could be formulated was very time consuming. In some cases because of the combinations of concepts that James had selected, a large amount of time was required only to come to the conclusion that a meaningful link could not be formulated. This process was found to be more effective when James had a good knowledge of the concepts involved. The main advantages associated with the use of this technique were that it provided James with an opportunity to establish the overall structure of the concept map before he was required to commit his map to paper. James also enjoyed being able to move the concepts around physically and he freely participated in the discussion with the researcher that allowed for the clarification of misconceptions that he held about the concepts.

The explicit teaching of the process of link construction involved the use of mental modelling in conjunction with responsive elaboration during the conversion of spoke word maps to spoke concept maps. While the use of these techniques by the
researcher enabled the students to decide when a meaningful link had been constructed during the conversion of spoke word maps to spoke concept maps, this awareness did not transfer to the process of meaningful link construction during the completion of the partially-complete concept maps.

The third means of scaffolding the process of link construction was based on the partially-completed scaffolding technique described by Chang et al. (2002). In the current study partially-completed concept maps were constructed using Inspiration 6. The main benefits associated with the use of the partially-completed concept maps were that they reassured the students that the concepts were in the correct position on the concept map and saved the time associated with deciding which concepts could be related. However, when the partially-completed concept maps replaced the use of concept cards in Trials 3 and 4, the motivational and encoding benefits associated with allowing James to physically manipulate the concept cards in order to decide which concepts could be related were eliminated.

While the use of concept cards and partially-completed concept maps each provided a means by which the concepts could be related, their use did not alleviate the difficulties that James and Sam experienced with the formulation of meaningful links. It was the use of interactive dialogue in the form of responsive elaboration and mental modelling combined with use of the partially-completed concept maps that proved to be the most powerful and time-effective tool in facilitating the development of conceptual understanding during the process of link construction. In addition, the physical presence of the maps facilitated the discussion process by focusing the students’ attention and allowing James and Sam to visualise the propositions that they
had proposed. The presence of the maps also facilitated the use of responsive elaboration and mental modelling in encouraging students to monitor their thinking. The effective use of the scaffolding techniques that were used to facilitate the process of link construction also relied on the use of the scaffolding techniques that had enabled James and Sam to consolidate their knowledge of individual key concepts. These observations are outlined in sections 4.2.12 and 5.2.6.

During the process of concept map construction, the formulation of meaningful propositions provided a means of evaluating students’ conceptual understanding (Fensham et al., 1982; Novak & Canas, 2006; Rye & Rubba, 2002; Williams, 1998). The observations made during the current study identify the considerable amount of scaffolding that some students require to facilitate the development of conceptual understanding while using concept mapping to summarise a chapter of a science text. In general, the findings of the study support the suggestion that the process of making connections between the elements of new information during the development of science understanding is not easily attained by many students, and that various models of teaching and learning have underestimated the amount of support that is necessary for such understanding to develop (Gallagher, 2002).

Discourse-based perspectives of the nature of understanding in science education emphasise the role of language in the development of scientific understanding (Hand & Prain, 2006; Klein, 2006; Yore & Treagust, 2006). In the current study, when predominantly verbal, language-based activities were used scaffold the development of conceptual understanding during the process of concept map construction, James did not benefit greatly from the level of verbal scaffolding that was provided.
However, by combining these verbal scaffolding activities with a number of additional visual scaffolding techniques the development of conceptual understanding during the process of concept map construction was enhanced.

The findings of this component of the study support the use of verbal and visual elaboration strategies to enable learners to remember and integrate new information (McNeal & Dwyer, 1999; Pressley et al., 1987; Willoughby, Porter, Belsito, & Yearsley, 1999), and the use of the multi-modal encoding of information to enhance the processing of information under conditions of high element interactivity (Sweller et al., 1998).

In this study individual differences in working memory functioning were suggested as one reason for the difficulties that some students experience with the development of conceptual knowledge during the process of concept map construction. This discussion continues with a consideration of the nature of the individual differences in working memory functioning that were identified in the three students who were assessed using the Working Memory Assessment Battery during Stages 1-3 of the study.

8.2 The Nature of Individual Differences in Working Memory Functioning Identified in the Study

In the current study, working memory profiles for three students who were experiencing difficulty with science learning were developed. The analysis of these profiles indicated that all three students performed in the below average range on measures of the functioning of the phonological loop component of working memory.
while the students’ overall functioning on measures of the visuo-spatial sketchpad and central executive fell within the average range. These findings provide support for the views that individual differences in learners’ cognitive profiles can be linked to specific types of learning difficulty (Archibald & Gathercole, 2006; Cornoldi, Rigoni, Tressoldi, & Vio, 1999; Heim & Keil, 2004; Kroesbergen, Van Luit, & Naglieri, 2003) and that individual differences in students’ working memory profiles can be linked to learning difficulties in particular subject areas (Gathercole & Pickering, 2000; Pickering & Gathercole, 2004).

In addition to difficulties with science learning, each of the students assessed with the Working Memory Assessment Battery in the current study had been identified on the Queensland Year 7 Tests in Aspects of Literacy and Numeracy (ACER, 2005) with poor performance in some areas of English and Mathematics, and could be broadly described as having general learning difficulties. Previous studies that have investigated the working memory functioning of students who were identified as having low achievement in the areas of English and Mathematics have identified difficulties with the functioning of the phonological loop, central executive and visuo-spatial sketchpad components of working memory (Pickering & Gathercole, 2004) and with the functioning of the central executive and visuo-spatial sketchpad components of working memory (Gathercole & Pickering, 2000). The three students who participated in the current study were found to have below average functioning of the phonological loop and average functioning in the visuo-spatial sketchpad and the central executive components of working memory. While the results obtained in the current study differ considerably from those obtained by Pickering and Gathercole (2004) and Gathercole and Pickering (2000), they provide support to the view that
students with general learning difficulties experience difficulty with some components of working memory functioning.

The findings of the current study are limited by the fact that only three students were assessed using the *Working Memory Assessment Battery*, however they do support the suggestion that some students who experience difficulty with science learning have limitations in some aspects of the functioning of their working memory system. In the case of the three students who were assessed in the current study, each of these students was found to be experiencing considerable difficulty with the storage and processing of verbal information in the phonological loop component of their working memory system.

This discussion continues with a consideration of how these individual differences in students’ working memory functioning may have influenced the effectiveness of the scaffolding activities that were used to facilitate the development of conceptual understanding during the process of concept map construction.

**8.3 The Impact of Individual Differences in Working Memory Functioning on the Development of Conceptual Understanding during Scaffolded Concept Map Construction**

Novak and Canas (2006) identify working memory as the site where all incoming information is organized and processed before it can be incorporated into long-term memory. The authors suggest that one of the reasons that concept mapping has been so useful in assisting meaningful learning is that it provides a template for the orderly
sequence of exchanges that occur between concepts and propositional frameworks when new knowledge is constructed in working memory. It is proposed that for meaningful learning to occur the learner must possess a well-organized knowledge base so that new information can be related to the learner’s prior knowledge and the motivation to use instructional strategies that facilitate the incorporation of new knowledge into the learner’s existing knowledge structures. Improving metacognitive awareness is suggested as one means of overcoming students’ difficulties with concept map construction. A considerable amount of research has linked the learner’s active use of metacognitive knowledge to quality learning outcomes in science (Brass et al., 2003; Conner, 2007; Gunstone, 1994).

In addition to the active use of metacognitive knowledge, Yore and Treagust (2006) use the term metacognition to include an indication of the student’s capacity to use scientific knowledge and identify the need to investigate the executive control of the cognitive operations that are central to the development of scientific literacy. In the current study, individual differences in students’ working memory capacity have been suggested as a reason that some students experience difficulty with concept map construction. This discussion continues with a consideration of the observations made during the study that can be used to support this suggestion.

In Stages 1, 2 and 3 of the study James, Sam and Tim were assessed using the Working Memory Assessment Battery. Each of these students was found to have limitations in the functioning of the phonological loop component of their working memory system. The span tests (i.e. Digits Forward and Auditory Word Memory) that
were used to assess this component of working memory are thought to provide a measure of the storage and rehearsal of verbal information in working memory.

In Trials 1 and 2 of Stage 1 of the study, a scaffolding sequence that relied heavily on the verbal processing of information was tried and evaluated with James. During these trials he was found to experience considerable difficulty with the extraction and representation of the conceptual information contained in the text and with the development of meaningful links on the concept maps. These observations are outlined in sections 4.2.3 and 4.2.6.

The model of working memory proposed by Baddeley (2002) can be used to predict the exchanges that would be required to take place in working memory during the process of knowledge construction when students are required to extract conceptual information from their science text. In order to identify and process the key conceptual knowledge, James needed to locate the key concepts in the text, to identify the information that related to each concept, to store and rehearse the information in the phonological loop component of working memory before transferring it to the episodic buffer of working memory where it could be combined with information that had been retrieved from long-term memory to form a new knowledge structure. He was then required to represent his newly constructed knowledge in the form of a written concept statement. Verbal corrective feedback was provided using responsive elaboration. One explanation for the difficulties that were experienced by James during the extraction, representation and correction processes in Trials 1 and 2 of the study is that the need to store and rehearse large amounts of verbal information in the
phonological loop component of his working memory overwhelmed the capacity of this component of his working memory system.

These observations are consistent with research that suggests that limitations in the functioning of the phonological loop component of working memory can impact on sentence memory (Mann et al., 1980), and the ability to infer the meaning of new vocabulary from context particularly when several ideas are spaced throughout the text (Cain et al., 2004). The suggestion of a link between difficulties with the functioning of working memory and the difficulties that James experienced with the representation of conceptual information in the written concept statements is supported by the model of writing proposed by McCutchen (2000) that predicts that working memory capacity can be a limiting factor in the writing process. The observations are also consistent with the suggestion that limitations in working memory capacity are linked to difficulties relating to the self-monitoring that occurs during the writing process (Hooper et al., 2002).

Interestingly, when an additional level of scaffolding in the form a spoke word maps was provided to assist with the extraction and representation of conceptual information in Trial 3 of the study, there was an improvement in the representation and recall of the conceptual information from the text. These observations are outlined in section 4.2.9. The depth of processing of the conceptual knowledge contained in the text was further enhanced when a step that required the conversion of spoke word maps to spoke concept maps was included in Trial 4, 5 and 6. These observations are outlined in section 4.2.12, 5.2.3 and 5.2.6. The observations outlined in these sections of the study support previous research that demonstrated the benefits
of the use of interactive strategies such as semantic mapping for vocabulary learning (Bos & Anders, 1990).

The model of working memory described by Baddeley (2002) predicts the benefits associated with the processing of information through both the verbal and visuo-spatial modes. It is suggested that the multi-modal encoding of information in the phonological loop and visuo-spatial sketchpad components of the working memory system provides a means of the dual storage of information in working memory and that as a result the processing of complex conceptual information in the working memory system can be enhanced (Baddeley, 2002; Sweller et al., 1998).

In the current study, the combined use of verbal and visual scaffolding activities enabled both James and Sam to progressively differentiate (Ausubel, 1968) their understanding of the concepts contained in the text. This in turn impacted on their recall of conceptual knowledge (Chi & Koesske, 1983; Garner, 1987, Whitney, 1987). It has been suggested that an increase in the automaticity of knowledge retrieval from long-term memory can decrease demand on working memory capacity during task performance (Kalyuga et al., 1998), and that as a result more processing resources can be allocated to the task of meaning construction during reading comprehension (Daneman & Carpenter, 1980; La Berge & Samuels, 1974). However in Trials 3, 4, 5 and 6 of the current study, even though James and Sam recalled the conceptual knowledge more readily, this was not sufficient to have a noticeable impact on their formulation of meaningful propositions.
The difficulties that James and Sam experienced with meaningful link construction were evident when they were required to formulate the language that would demonstrate an understanding of the relationship between concepts and when they were required to determine whether or not a meaningful link had been constructed. During map construction, James and Sam either failed to monitor whether their answers made sense or when questioned by the researcher, realised that they did not, but required a considerable degree of assistance with the development of meaningful links. These difficulties with the evaluation meaningful propositions were also a feature of the exchanges that occurred between each of these students and the researcher when they were assessed using the Sentence Assembly subtest of the CELFST-4 test even though the level of conceptual complexity of the information that was to be remembered and reorganised in the test was considerably less than the information contained in the science text. These observations are outlined in sections 4.2.12, 5.2.6 and 6.3.

The model of working memory proposed by Baddeley (2002) can be used to predict the exchanges that would be required to take place during the process of knowledge construction when students are required to develop propositions on a concept map. To construct a link between two concepts the students needed to select two concepts from the concept list, to retrieve from long-term memory the information that related to each of these concepts, to evaluate this information to decide if a meaningful link could be formed and then to formulate a meaningful link, either independently or with the aid of the assistance provided by the researcher through the use of mental modelling and responsive elaboration. Novak and Canas (2006) refer to the process of
link construction as being developed piece-by-piece using a framework of interacting concepts and propositions.

While the visuo-spatial scaffolding provided by the spoke word maps and the partially-completed concept maps provided the students with an additional means of holding the concepts in memory they did not, on their own, trigger automatic link formulation. Instead, the gradual elaboration and clarification of concept meanings that facilitated the restructuring of existing schemata (Ausubel, 1968) during the process of link construction required the extensive use of verbal scaffolding that involved the use of responsive elaboration, mental modelling and writing. The presence of the visuo-spatial scaffolds in the form of spoke word maps and partially-completed concept maps facilitated this high level of language interaction that was required for the verbal scaffolding to occur.

One explanation for the gradual the development of conceptual understanding that is described in sections 4.2.12, 5.2.6 and 6.2 is that the multi-modal processing of information in the episodic buffer of working memory (Nesbit & Adesope, 2006; Reed, 2006; Sweller et al., 1998) facilitated the restructuring process that led to the creation of new schemata that could be stored in long-term memory. These new conceptual schemata were then used by James and Sam when they were required to represent their conceptual understanding in the extended recall conceptual questions that were completed independently after whole-chapter concept maps had been constructed. These writing samples are presented in sections 4.2.12 and 5.2.6.
Because the capacity to maintain information in the episodic buffer depends not only on the capacity of the buffer itself but also on the capacities of the two domain-specific storage systems and the central executive (Baddeley, 2002), it could be concluded that the difficulties that James and Sam experienced with the formulation of propositions during concept map construction were influenced by difficulties in maintaining and rehearsing verbal information in the phonological loop component of working memory. Difficulties associated with the rehearsal of information in the phonological loop could be related to difficulties associated with holding information in the episodic buffer long enough to decide if the information made sense.

It has been suggested the role of the central executive is to focus, divide and switch available attention and to maintain information in the service of ongoing activities such as comprehension (Baddeley, 2002). Therefore, any difficulty in storing and rehearsing information in the phonological loop would impact amount of attention that the central executive would be required to devote to the maintenance of verbal information during the formulation of meaningful propositions (Baddeley et al., 2001; Kane et al., 2004). These difficulties with the storage and maintenance of verbal information would make it difficult for the students to monitor the construction of meaningful propositions. This argument bears some similarity to the view that children’s capacity to hold information in working memory is related to their acquisition of not only a theory of mind, but also to the acquisition of other higher order conceptual structures (Gordon & Olson, 1998). The suggestion that the difficulties James and Sam experienced with the formulation of meaningful propositions were linked to limitations in working memory capacity is also supported by the model of language comprehension proposed by Just and Carpenter (1992). The
authors relate the ability to activate multiple interpretations of information to individual differences in working memory capacity. It is suggested that individuals with high working memory capacity are more able to maintain alternative interpretations of a sentence in working memory. The difficulties that James and Sam experienced with the maintenance of alternate interpretations of sentences in working memory became particularly evident when they were assessed used the *Sentence Assembly* subtest of the CELFST-4 test. These observations are outlined in section 6.3.

In this study, two conceptions of metacognition have been identified. The first of these uses the term metacognition to describe self-knowledge about cognitive states and processes. Within this view two broad categories of metacognition were identified. These were self-appraisal of cognition and self-management of thinking (Reeve & Brown, 1985; Jacobs & Paris, 1987). Research in science education has emphasised the importance of students’ metacognitive development (Case & Gunstone, 2006; Gunstone, 1994; Novak & Canas, 2006; Schraw et al., 2006) and the need for learners to take control of their own learning and actively engage in the meaning construction process (Brass et al., 2003; Conner, 2007).

Borkowski et al., (1987) suggest that the use of metamemorial knowledge results from a developmental process that involves changes to metacognitive knowledge over long periods of time. Gunstone (1994) uses the term enhancing metacognition to describe the development of students’ more appropriate metacognitive views. Brass et al., (2003) suggest that research that aims to investigate the development of enhanced metacognition should be embedded within the content of real learning tasks.
Gunstone (1994) reports on a study that was conducted with a group of trainee science teachers. While it is acknowledged that these science graduates are not high school learners, it is suggested that they share one characteristic that has possible relevance to high school contexts. That is, they had considerable propositional knowledge but inadequate conceptual knowledge of the physics content to be studied. It is suggested that for the enhancement of metacognition to occur, that the science content needs to be neither completely unfamiliar nor already understood.

The second conception of metacognition is related to an information processing view of human memory in which a limited-capacity central executive guides the overall functioning of the system. From this perspective, executive control is identified as having a central role in controlling the construction of meaning in working memory (Baddeley, 2002; Reeve & Brown 1985; Yore & Treagust, 2006). In the current study, the overall operation of the working memory system has been described in Chapter 2.

In Trials 4, 5 and 6 of the study, even though James and Sam improved their recall of propositional knowledge through the completion of written concept statements and spoke concept maps and their metacognitive awareness of the need to actively engage in the learning process and to monitor the formulation of meaningful propositions through the use of mental modelling and the completion of spoke concept maps, this improvement in domain-specific and metacognitive knowledge did not have a marked impact on meaningful link construction when James and Sam were required to complete the partially-completed concept maps. In this study it is suggested that an additional factor, individual differences in working memory capacity, may have
influenced James’s and Sam’s difficulties with the monitoring of meaningful link construction during the concept mapping task. The model of metacognitive development proposed by Borkowski et al., (1987) would also suggest that these difficulties with the monitoring of meaning construction could also have the potential to impact on the students’ overall development of metamemorial knowledge.

In the current study James and Sam were shown to experience considerable difficulty with the storage and rehearsal of verbal information in the phonological loop of working memory. This difficulty may have had the effect of consuming a considerable amount the limited-capacity resources of the central executive. The result of this allocation of working memory capacity to the storage and rehearsal of verbal information may have been that the central executive may not have had sufficient available capacity to control and maintain the construction of meaning in working memory (Baddeley, 2002; Kane et al., 2004; Yore & Treagust, 2006).

In this way the difficulties that James and Sam experienced with the monitoring of meaningful link construction may have been related to the difficulty that they experienced with maintaining concepts and propositions in working memory long enough to decide whether or not a meaningful link had been created. From this perspective, James and Sam would be described not as the inactive strategy users described by Torgensen (1982), but as learners whose strategy utilization was limited by the capacity of their working memory system (Imbo & Vandierendonck, 2007; Keeler & Swanson, 2001; Woody-Dorning & Miller, 2001).
While a number of factors such as domain-specific knowledge, metacognitive knowledge and the high cognitive load associated with complex task performance (Chang et al., 2002; Katayama & Robinson, 2000; Novak & Canas, 2006) have been linked to the difficulties that some students experience with concept map construction, in the current study individual differences in working memory capacity are suggested as an additional factor that may be linked to the difficulties that some students experience with the concept-mapping process. These difficulties with working memory functioning have the potential to impact not only on the development of understanding of individual concepts (Cain et al., 2004) but also on the construction of meaningful propositions, the formulation of which is an essential means of representing students’ understanding (Fensham, et al., 1982; Novak & Canas, 2006).

Each of the students who were assessed using the Working Memory Assessment Battery in the current study were found to experience difficulty with the storage and rehearsal of verbal information in the phonological loop of working memory, with a relative strength in the visuo-spatial and central executive components of the assessment. However, the students also exhibited individual differences in their performance on the subtests that were used to measure performance on these three components of the working memory. For example, one of the students, Tim, performed in the low average range on both measures of the central executive and in the below average range on the Memory for Location subtest of the visuo-spatial component of the Working Memory Assessment Battery. One explanation for the marked level of difficulty that Tim experienced with the extraction of information from the text, with the use of Inspiration 6 and with the process of link construction may be related to the individual differences that were identified in Tim’s working
memory profile. Observations made by the teacher aide during the implementation of
the scaffolded concept-mapping process suggest that difficulties with memory for
location may have impacted on Tim’s memory and use of the components of the
Inspiration 6 program. These observations are outlined in section 7.2.3.1. This
difficulty meant that more time was required for Tim to familiarise himself with the
use of the program. In contrast, both James and Sam had a relative strength in the area
of visuo-spatial processing and were observed to master the operation of Inspiration 6
more quickly.

Tim’s working memory assessment profile also indicated that the functioning of the
central executive component of working memory was in the low average range. The
combined difficulties associated with the storage and rehearsal of verbal information
and with the storage of spatial information would have placed additional strains on the
amount of attentional resources that were available for the construction of conceptual
understanding in the episodic buffer component of working memory. The
observations made by the teacher aide during the concept-mapping process also
described these difficulties with meaning construction. These observations are
outlined in section 7.2.3.1. While the scaffolding of the concept-mapping process for
Tim followed the same overall sequence that was used with the other two students,
the magnitude and variation in the individual differences in his working memory
profile proved to be predictive of the amount of additional time and assistance that
was needed for each of the scaffolding activities to be completed.

Novak and Canas (2006) suggest that one of the reasons that students experience
difficulty with concept map construction is that they are committed to a rote mode of
learning. In order to overcome these difficulties it is suggested that students are given instruction about the functioning of cognitive mechanisms and knowledge organization when they are required to develop concept maps. While such metacognitive knowledge contributes to students’ understanding of the knowledge construction process, it may not be sufficient to compensate for difficulties with concept map construction that may be related to individual differences in working memory capacity.

In the current study individual differences in working memory functioning have been suggested as an additional reason for the difficulties that some students were observed to experience with the development of conceptual knowledge during concept map construction. The findings of the current study have a number of implications for teaching practice. These implications are now discussed.

8.4 Implications of the Study for Teaching Practice

The previous discussion has suggested how individual differences in the functioning of the components of students’ working memory system can impact on students’ learning outcomes when different combinations of instructional techniques are used. The instructional approach developed in the current study identified a specific sequence and combination of scaffolding techniques that were used to assist students with the development of their knowledge and understanding of the information contained in a science text. The development of this scaffolded instructional approach has identified a number of features that should be considered by classroom teachers when they are planning instructional interventions for students who are experiencing difficulty with science learning.
The first is the use of a combination of multi-modal instructional techniques for students who experience difficulty with the processing of verbal information. In the current study, the sequence of scaffolding techniques was developed with students who were shown to have limitations in the functioning of the phonological loop component of their working memory system with a relative strength in visuo-spatial and central executive processing. The observations outlined in sections 4.2.12, 5.2.6 and 6.2 of the study highlight the impact that specific sequences and combinations of scaffolding techniques can have on the performance of students with this working memory profile. For these students the multi-modal encoding of new information (Gerlic & Jausovec, 1999; Nesbit & Adesope, 2006; Sweller et al., 1998) provided by the inclusion of visual scaffolding activities in the instructional sequence provided a means of enhancing the processing of new verbal information through the use of their visual pathway and facilitated both the consolidation of conceptual knowledge and the development of connected understanding. In addition, the combined use of verbal and visual scaffolding facilitated the use of language as a tool for the development of conceptual understanding (Hand & Prain, 2006; Klein, 2006, Yore & Treagust, 2006).

It should also be noted that the intensive scaffolding that was required for the students who participated in the current study to develop and represent their understanding of new conceptual information required the allocation of sufficient time for that conceptual change to occur. The results of the study support the suggestion that students needed to be given enough time to identify and express their conceptions and to reflect on, to evaluate and to restructure their ideas (Driver & Oldham, 1986). These opportunities were provided through the use of responsive elaboration and
mental modelling and through the completion of writing tasks in the form of written concept statements and extended recall conceptual questions.

Secondly, the observations made during the study have been used to suggest how individual differences in working memory functioning can influence the development of conceptual knowledge and highlight the need for teachers to have an awareness of the individual differences in cognitive ability that students bring to classroom learning so that methods of instruction can be directly related to students’ individual learning needs (Airasian & Walsh, 1997; Bischoff & Anderson, 1998; Hand & Prain, 2006, Taber, 2000). This need for teachers to have an awareness of the individual differences that students bring to classroom learning supports the use of student learning profiles as a means of enabling teachers to determine the best ways of improving the learning outcomes of particular students (Dultz, 1999).

The usefulness of broadly-based cognitive profiles in enabling teachers to provide more individualized instructional interventions is also supported by Kroesbergen et al., (2003). In this study the link between students’ cognitive profiles and learning difficulties in mathematics was investigated. It was concluded that the inclusion of additional learning characteristics such as reading and spelling performance would further define the heterogeneity of the group of students who were experiencing difficulty with learning in mathematics and as a result facilitate the development of instructional interventions.

The third implication of the findings of the study for classroom teaching practice is related to the importance of cognitive load as a factor that needs to be carefully
managed during the implementation of instruction (Kalyuga et al., 1998; Sweller at al., 1998). In the current study, when a high level of cognitive load was associated with the extraction and representation of conceptual knowledge from the text, and with the formulation of meaningful propositions on the concept maps students’ experienced difficulty with self-correction and with monitoring of their performance. When the pressures of high cognitive load were reduced: for example, by scaffolding the construction of the written concept statements through the use of the spoke word maps, an improvement with the extraction and representation of information was noted.

The fourth implication of the observations made during the current study for classroom teaching practice is associated with the incorporation of interactive technology as a tool to facilitate program delivery. The observations outlined in sections 4.2.12 and 5.2.6 support the suggestions that the use of computer-generated concept mapping not only contributes to students’ level of motivation and persistence with writing tasks (Sturm & Rankin-Erickson, 2002) but also fosters their engagement in the depth of processing that is required for the development of conceptual understanding (Blankenship et al., 2005).

Finally, the findings of the study provide some support for the use of teacher aides as an means of facilitating the delivery of the scaffolded concept mapping process in the context of the School’s Learning Support Centre. However, the observations made during the study support previous research that suggests that the effectiveness of the use of teacher aides is reliant on the kinds of additional support that they are given (Axford, 2007; Woolley & Hay, 2007).
In the current study the development of concept maps provided James and Sam with a means of visualising the relationships between the key concepts contained in the textbook chapters. For these students the use of the scaffolding techniques enabled the representation of conceptual understanding in the form of a whole-chapter concept map to occur (Kinchin et al., 2000). This scaffolding sequence could be incorporated into regular classroom practice by providing students with the opportunity to complete each component of the whole-chapter concept map at particular junctures during the study of a science chapter.

In order to enable teachers to implement the instructional sequence in the regular science classroom teachers would need to be given training in the use of each of the scaffolding techniques. In addition, students would require regular computer access. The use of interactive discussion that is an essential component of the scaffolding process could be provided by whole-class teacher led discussion with additional intensive support provided for some students through the use of teacher aide assistance.

In conclusion, in this study the use of design-based research provided an effective means of connecting theoretical research with classroom teaching practice. The use of the continuous cycles of design, enactment, analysis and redesign provided the researcher with an organised framework for the systematic observation of students’ performance and for the evaluation of the learning outcomes that resulted from the use of an instructional intervention that could be gradually developed to suit the learning needs of this particular group of students.
Conclusions and Future Directions

One of the key requirements of the development of scientific understanding is the need for all students to access the cognitive tools that enable them to read and evaluate science texts (Gajria et al., 2007; Hand & Prain, 2006; Millar, 2006; Norris & Phillips, 2003). Concept mapping is one cognitive tool that has been widely used to facilitate the development of understanding in science (Novak & Canas, 2006).

The aim of this study was to investigate whether scaffolded concept mapping could be used to facilitate the development of conceptual understanding when students who experience difficulty with science learning used concept mapping to summarise a chapter of a science text. The study also sought to investigate the extent to which students who were experiencing difficulty with science learning have individual differences in the functioning of working memory and whether these differences in working memory functioning could be used to explain the observed changes in the development of conceptual knowledge that occurred when these students used a scaffolded concept mapping strategy. A design-based research methodology (Design-Based Research Collective, 2003; Shavelson et al., 2003) was used to investigate aspects of the interaction between the learner, the learning environment and the instructional activities during the performance of a concept-mapping task.

The students who were assessed using the Working Memory Assessment Battery in the current study were shown to have a range of individual differences in the functioning of the phonological loop, visuo-spatial sketchpad and central executive components of
their working memory system. In particular, all three students were found to have difficulties with the functioning of the verbal phonological loop component of working memory.

The theoretical framework that identified the central role of working memory in the construction of conceptual knowledge (Baddeley, 2002; Novak & Canas, 2006; Yore & Treagust, 2006) proved to be a useful approach for conceptualizing and explaining the difficulties that some students experience during the concept-mapping process and in explaining the impact of different scaffolding techniques on the process of knowledge construction. The findings of this study support the use of multi-component instructional techniques that target different aspects of the knowledge construction process with students who experience difficulty with understanding of science texts (Baker et al., 2002; Gajria et al., 2007).

One of the aims of design-based research is to investigate cognition in context while at the same time advancing theory that will be of benefit to others (Barab & Squire, 2004). In general, the observations made during this study support the view that there is a need in science education for the development of models of teaching and learning that incorporate current views of cognitive science (Klein, 2006; Prain & Waldrip, 2009; Yore & Treagust, 2006). Specifically, the findings of the study support the use of multi-modal instructional techniques to accommodate the individual differences that students bring to classroom learning (Hand & Prain, 2006; Prain & Waldrip, 2009; Yore & Treagust, 2006) and highlight the need to consider the individual differences in students’ capacity to use scientific knowledge when designing science instruction (Marcus et al., 1996; Yore & Treagust, 2006).
While the findings of the study support the suggestion that individual differences in the functioning of the components of students’ working memory can impact on the use of a concept mapping strategy when they are required to summarise a chapter of a science text, these findings are limited by the fact that only three male students were assessed using the *Working Memory Assessment Battery*. Also, each of these students was identified with broadly the same working memory profile. Further research aimed at investigating whether particular sequences and combinations of scaffolding activities suit the learning needs of students with different working memory profiles is required.

The instructional sequence developed in the current study was tried and evaluated using teacher aide assistance within the School’s Learning Support Centre. While the perceptions provided by the teacher aides provide some support for the implementation of the scaffolded concept mapping process using teacher aide assistance, these observations are limited by the fact that no evaluation of students’ concept maps was undertaken. Further research is required to evaluate students’ learning outcomes when scaffolded concept mapping is implemented using teacher aide assistance. One of the main observations made throughout the study was the amount of support that some students required to develop conceptual understanding. Further research is also required to identify whether the instructional sequence developed in this study can be used effectively in science classrooms with teacher aide assistance. Future research could be aimed at investigating the following research questions.
1. To what extent do students who experience difficulty with science learning have working memory profiles that identify individual differences in the functioning of the phonological loop, visuo-spatial sketchpad and central executive components of their working memory system?

2. Can these individual differences in working memory functioning be used to explain observed differences in the effectiveness of different instructional sequences used to facilitate the process of concept map construction?

3. To what extent can scaffolded concept mapping be implemented in science classrooms to improve students’ learning outcomes using teacher aide assistance?
This appendix contains samples of curriculum materials that were included in the Curriculum Booklets provided to the teacher aides. The use of these materials enabled the teacher aides to facilitate the students’ study of the science chapters. The sample materials included in the Appendix were used in the study of the chapter entitled “Living with Acids and Bases”.

The sample curriculum materials include copies of:

1. The key concept word list divided into concept subsets.
2. Individual key concept word maps for each concept subset.
3. A template for student-constructed written concept statements for the key concepts in each concept subset.
4. A template for the partially-completed concept maps for each concept subset.
5. A completed whole-chapter concept map.
6. A template for the extended recall conceptual questions.
Science World Year 9
Chapter 9 Living with Acids and Bases

Acids
Bases
Acids in body
Acids in food
Mucus

Indicator
pH Scale
Ion

Salts
Neutralization
Acid rain
ACIDS

CONCENTRATED
CORROSIVE
SOUR TASTE

DILUTE LARGE AMOUNTS OF WATER

EXAMPLES ARE
HYDROCHLORIC, SULPHURIC, LEMON JUICE

ALKALI-SOLUBLE BASE
NEUTRALISE ACIDS

BASES
EXAMPLES ARE SODIUM HYDROXIDE OVEN CLEANERS

BACTERIA IN MOUTH PRODUCE ACIDS

HCl STOMACH BACTERIA

ACIDS IN BODY

GASTRIC JUICES BREAKS DOWN FOOD

GASTRIC JUICES CONTAINS HCl

PROTECTS STOMACH WALL FROM GASTRIC JUICES

MUCOUS
LUBRICATES STOMACH WALL

ACIDS IN FOOD

BAKING POWDER AND SELF-RAISING FLOUR MAKES CAKES RISE

VINEGAR PRESERVES FOOD
Science World 9
Chapter 9
LIVING WITH ACIDS AND BASES

1. Acids

2. Bases

3. Acids in body

4. Acids in food

5. Mucus
Universal indicator has many colours

Examples are Litmus, Bromothymol Blue

Has two colours

Indicator

Change colour

Tell if solution is Acidic, Basic, Neutral

pH Scale

Scale from 1 to 14

Basic solution pH greater than 7

Neutral solution pH 7

Acidic pH less than 7

pH measures hydrogen ion concentration H+

Hydrogen atoms lose a electron-

Hydrogen ion

Atoms that have lost or gained electrons

Positive and negative ions attract each other

Metals form positive ions

Basic solutions contain OH-

Ions carry the electric current through solutions

Non metals form negative ions

Acids contain hydrogen ions (H+)

Measure using an indicator

Ion

Neutral solution pH7
6. Indicator

7. pH scale

8. Ion
Salts

Neutralisation

1. Acid Rain
ScienceWorld 9
Chapter 9

1. Normal rainwater has a pH of about 6, distilled water has a pH of 7 and acid rain can have a pH of as low as 2. What does the pH value tell you about the concentration of hydrogen ions in each of the water samples?

2. Explain how you could work out the pH of a sample of soil.

3. In the laboratory you have been given two solutions which are either acidic or basic. Give three different methods that you could use to decide whether either of the solutions is acidic.
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