Inhibition & mental effort: a moderation hypothesis

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Inhibition & Mental Effort: A Moderation Hypothesis

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This thesis is presented as part of the requirements for the award of the degree of Doctor of Philosophy

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Thesis Declaration

I certify that the work presented in this thesis is, to the best of my knowledge and belief, original, except as acknowledged in the text, and that the material has not been submitted, either in whole or in part, for a degree at this or any other university.

I acknowledge that I have read and understood the University's rules, requirements, procedures and policy relating to my higher degree research award and to my thesis. I certify that I have complied with the rules, requirements, procedures and policy of the University (as they may be from time to time).

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Abstract

This investigation addresses the relationship between cognitive inhibition as an executive function of the working memory system and cognitive load as the mental effort experienced in relation to classroom learning. The argument advanced and tested is that cognitive inhibition moderates cognitive load, and thereby provides an explanatory mechanism for extrinsic forms of cognitive load. The implications of this relationship are identified and discussed in relation to instructional design.

The relevant literature shows a limited appreciation of the importance of the role played by cognitive inhibition in relation to cognitive load, and, indeed, in relation to learning outcomes in general. Against this background, an empirical investigation of how inhibitory processing differences interact with cognitive load was performed for 114 Year-8 (8th-grade) students. Cognitive inhibition for each student was estimated using the Attentional Networks Test (Posner & Fan, 2005). Student self-reports were employed to estimate individual cognitive load. The relationship between cognitive inhibition and cognitive load was examined across 16 different classroom learning activities, separately involving four teachers. Correlation matrices and ANOVA tests were used to analyse relationships. Achievement outcomes, as indicated by teacher-awarded marks, were also analysed in relation to both cognitive inhibition and cognitive load.

A statistically significant relationship between cognitive inhibition and cognitive load occurred in classes conducted by three of the four teachers. This relationship remained statistically significant even when controlling for a range of other individual differences. The strength of this relationship, however, varied according to the style of the teachers. Achievement outcomes were not significantly related to cognitive inhibition, yet the direction of the association consistently found does suggest that a relationship also exists between cognitive inhibition and achievement outcomes.

The overall results support the need for cognitive inhibition to be considered as a distinct element in the design of a comprehensive, cognitive-based pedagogy. In light of the results, two instructional strategies that involve reduced mental effort and increased instructional efficiency are proposed. Future research investigating the efficacy of these strategies in terms of their impact on cognitive load and achievement outcomes is discussed.
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CHAPTER 1: INTRODUCTION TO THE INVESTIGATION

Strategies, knowledge base, and other “high-cognitive” explanations are not so much wrong as they are incomplete. Effective thinking and remembering require more than strategies and knowledge, they also require a capacity for controlling interference from extraneous sources. (Dempster & Brainerd, 1995, p. 402).

1.0 Introduction

This investigation concerns the human ability to inhibit distracting information as a means of regulating cognitive load during the process of learning. It was prompted by a realisation that, while a great deal of attention has traditionally been given to ways of developing a learner’s ability to attend to salient task-relevant information, insufficient attention has been given to how to improve a learner’s ability to inhibit distracting, task-irrelevant information. This chapter introduces the investigation, outlines the conceptual framework adopted, identifies the need for the investigation, documents the specific research questions and related hypotheses, introduces the research methodology and reviews the nature of the data collected. Limitations of the investigation are noted, key terms in the research are defined, and an outline of each of the chapters in the thesis is provided.

Underpinning the investigation is a theory of cognitive learning that involves the concept of working memory (Anderson, 2000; Ashman & Conway, 1997; Baddeley, 2001; Becker, Isaac, & Hynd, 1987; Denckla, 1996; Engle, 2002; Fan et al., 2002; Gathercole, 1999; Karatekin, 2004; Pickering & Gathercole, 2004; Winne, 1995). Within this theory, learning-related processing is affected by the operation of an individual’s working-memory (WM) system, where executive control mechanisms regulate key processes that include attentional sequencing, the inhibition of irrelevant information, and the organisation of information. In this investigation, the topic of interest concerns the mechanisms associated with the inhibition of irrelevant information. The investigation seeks specifically to examine the roles played by response monitoring, which is essential to maintaining attention to task-relevant information (Corbetta et al., 1995) and error detection, which is necessary for identifying irrelevant or conflicting information (Cohen, Botvinick, & Carter, 2000), as these impact upon cognitive learning.
1.2 Conceptual framework

The literature on cognitive learning is rich and complex. Fodor and others (Fodor, 1985; Pinker, 1997; Sterelny, 1990) have postulated that, although primitive sensory encoding may initially control the way information is processed by the human brain, it is the executive control mechanisms of WM that ultimately control the assigning of information in meaningful ways, by encoding it into long-term memory, holding it in short-term memory stores, or suppressing it from further processing. Assigning information requires some form of executive control over the assignment process, most likely involving the associative relevance of the information. According to the principle of association, and in light of understandings of human learning provided by, for example, schema theory and propositional network theory, the brain organises and accesses information by means of the mapping of categorical and fine-grained associations that occur for information stored in long-term memory (cf., Anderson, 2000; Alba & Hasher, 1983; Rothermund & Wentura, 2004; Schneider & Shiffrin, 1977; Schunk, 1996; Wilding, 1999).

Having control over the way information is assigned suggests that the main purpose of the WM executive control mechanisms is to selectively process information, a function that is critical to learning because it the basis for task-switching ability, that is, the ability to switch effectively from one task to another (Gathercole, 1999). Task switching requires the ability to inhibit distracting or non-relevant information during learning. This ability stems from the inhibitory executive control mechanism, which has been suggested as providing the basis for selective attentional focus (Bjorklund & Harnishfeger, 1990; Davies, Taylor & Jones, 1984; Karatekin, 2004; Pascual-Leone, 2000). The focus of this investigation concerns the role of the inhibitory executive control function, particularly in terms of how individual differences in inhibitory ability correspond to the amount of cognitive load experienced by students.

From an information-processing perspective, the central theme in learning is limited-capacity processing (Byrnes, 2001; Sweller, van Merrienboer, & Paas, 1998). This is because active WM processing is limited to between 5 and 9 “bits” of
information at any given time for most individuals (Miller, 1956; Baddeley, 1986). The notion of limited capacity reminds us that the executive control mechanisms related to selective attentional processing are adaptive. They serve to selectively adapt situational processing demands to the processing capacities of individual learners. Viewed within the broad divisions of task-relevant versus task-irrelevant control functions, the role of inhibition is important because the inhibitory control function preserves and maintains processing relevancy in line with the individual’s capacity constraints. Thus, the notion of limited capacity processing requires that the inhibitory function be taken into account in relation to overall task demands.

In educational terms, the principle of limited capacity indicates that instructional approaches need to be designed in a way that avoids excessive demands being made at the WM level. This is because instruction that does cause excessive demands on WM places a higher cognitive load (processing demand or mental effort) upon the processing of instructional information. Cognitive Load Theory (CLT, cf. Sweller, 1994; Sweller, et al., 1998) is a theory of instructional design that is concerned with the impact of mental effort in relation to capacity limitations. This theory examines the types of extraneous and intrinsic processing loads that instruction places on the WM system, and how these loads affect the experience of mental effort. The theory thus provides an approach to instructional design in which the interactions between mental demand and processing effort are brought to the fore. The WM executive mechanisms are integral to CLT because they manage the capacity constraints of human processing, and thereby mediate the amount of cognitive load placed on processing during the learning process (Di Vesta, & Di Cintio, 1997; Sweller, 1994; Sweller, van Merrienboer, & Paas, 1998). It seems fair to say, therefore, that if individual learning outcomes are to be supported and improved through a cognitive approach to designing classroom instruction, this will need to involve the targeted deployment of executive WM processes in a way that recognises and supports the overall capacity constraints of individual students.

In this respect, most cognitive approaches to designing classroom instruction have recognised that the processing of instructional information is improved through the use of various mnemonic strategies, which condense and elaborate task-relevant information in order to address the limitations of WM. Yet the role of task-irrelevant
information in relation to limited capacity has not been equally identified and dealt with. Thus, whether or not limited capacity is affected significantly by the processing of irrelevant information, and whether this might affect the level of cognitive load experienced in relation to learning, are areas of cognitive pedagogy that require further examination. The need to develop a greater understanding of the relationship between inhibitory processing and mental effort therefore appears to represent an appropriate imperative to the area of cognitive pedagogy. Such an imperative may also be quite timely, as it has been suggested that, to date, the educational application of cognitive and neuropsychological knowledge has not been well supported by the classroom teacher (Byrnes & Fox, 1998; Conway & Ashman, 1991; Goswami, 2004; Smith, 2004). The current study therefore seeks to provide both relevant and timely knowledge to the area of applied cognitive learning theory, based on the role of inhibition in relation to cognitive load.

A review of the research on WM in relation to learning and development reveals that an apparent gap does exist specifically in relation to our understanding of inhibitory processing and learning. Although a great deal of research has investigated the relationship between WM processes and learning, most of this work has been directed at issues of memory or memory function (Anderson, 1995, 2000; Ericsson, Chase, & Faloon, 1980; Reynolds, 1993; Rose, 1992), the limited capacity of WM and the attentional system (Baddeley, 1986; Spear & Riccio, 1994; Just & Carpenter, 1987), the relationship between selective attention and the automatic processing of information (Sweller, 1999; Stanovich, 2000), and the construction of the meaningful elaboration of information (Kintsch, 1988; Pressley & Wharton-McDonald, 1997). As well, a great deal of research investigating WM and executive processing in relation to learning has focused on why the learning is easier or more difficult in relation to development (e.g., Swanson, 1999; Towse, Hitch, & Hutton, 1998), to task difficulty and strategy use (Chi, Glaser, & Rees, 1982; Guttentag, 1997; Miller, 1994), or to specific learning difficulties (Gathercole & Pickering, 2000; Pennington & Ozonoff, 1996).

In contrast, fewer researchers have attempted to connect the executive WM process of inhibition to specific classroom strategies (although related studies have been carried out on interference and the nature of forgetting, see Greene, 1992; Waugh &
Norman, 1965), and only a handful of studies have examined the role of specific WM executive functions in relation to inhibiting irrelevant information (although see Barrouillet, Fayol, & Lathuliere, 1997; Passolunghi, Cornoldi, & de Liberto, 1999; Swanson, Cooney, and Brock, 1993). None of these studies, however, has attempted to profile the underlying relationships that exist between the inhibitory function and mental effort within a mainstream classroom context.

This investigation seeks to clarify whether the WM executive process that deals with irrelevant, distracting, or conflicting information (the inhibitory function) affects mental effort in relation to learning. This relationship is explored within the context of individual differences. It is the primary goal of the research to distinguish how individual differences in the ability to suppress or inhibit information correspond to mental effort on the part of the learner, within the context of authentic classroom learning. The research also seeks to identify whether or not the relationship between inhibitory activity and mental effort is able to further exert a moderating influence upon achievement outcomes as they also occur with the same classroom context.

1.3 Need for an investigation

Several different areas of WM function have been related to learning at the classroom level, and many of these areas seem to involve, or at least imply, the need to inhibit distracting or other forms of irrelevant information. For example, research has shown that writing skills, important to academic progress and learning in general, require distinct yet overlapping executive WM processes that allow the learner to plan, draft, and revise the writing (Baker & Hubbard, 2002). These various processes take place via focusing attention to organise and collect information (Berninger, Cartwright, Yates, Swanson, & Abbott, 1994), encoding and storing the information in relation to existing knowledge (Abbott & Berninger, 1993), and setting forward goals pertaining to the purpose and style of the writing itself (Graham, Schwartz, & MacArthur, 1993). The overlapping nature of these processes necessitates the inhibition of some information, in order to selectively attend to other information.
Additionally, these same processes can also interfere with effective writing (Berninger & Colwell, 1985), due to faulty response suppression in relation to the forward planning of specific sequences and actions (Englert & Raphael, 1988). This represents an inhibitory processing deficit that can result in poorer information integration as well as lower cognitive self-regulation (cf. Denkla, 1996). Effective writing appears to require an efficient inhibitory response.

With respect to numeracy, Riley, Greeno, and Heller (1983), and Kintsch and Greeno (1985), have argued that mathematical problem solving involves the controlled use of schemata, and that the acquisition and manipulation of schemata are central to mathematical problem solving. Mathematical operations depend on the use of both algorithms (rule-driven operations by which a particular type of problem is approached) and conceptual understanding (including strategy type). Algorithms link networks of schemata together, to guide the computations needed to solve arithmetic problems (cf. Mayer & Hegarty, 1996), and conceptual understanding drives the way problems are conceptually represented (Bransford, Zech, Schwartz et al., 1996).

Riley et al. (1983) suggested that when particular arithmetic problems are presented, problem schemata (based on the semantic content of the problem) are activated and held in WM, action schemata (algorithmic operations) are then compared against the type of problem for possible application, and strategic knowledge (self-regulatory knowledge, representative of an executive decision-making process) is then applied to the selected actions in order to sequence a possible solution. Learning to solve mathematical problems thus involves the simultaneous processing of information from short-term memory store, the use of conditional or rule-driven information, and metacognitive, discriminatory self-regulation processes. Again, there exists an overlapping of information processing required to complete the learning task. The presence of concurrent processing tasks in this conception of mathematical problem solving implies an efficient inhibitory mechanism as being central to successful task outcomes.

For both literacy and numeracy learning, the key to understanding the relationship between information processing and the learning seems to depend on being
able to selectively attend to task-relevant information while simultaneously inhibiting task-irrelevant information. Indeed, it would seem that processing for learning involves an intense activation/suppression process, and as such depends to a large degree upon the executive ability to inhibit irrelevant, distracting, and conflicting information in relation to instructional inputs that may vary in terms of activation priming. An example of how inhibitory function might be required at higher levels of executive control in relation to such processing can be seen in schemata that are only partially or indirectly relevant to the learning task. Such schemata would contain information that was partially or inconsistently activated, requiring executive inhibitory control to maintain the information just below the task-relevant activation threshold during processing. Inhibitory control for this sort of processing would involve extensive ongoing monitoring and suppression, in order to maintain the near-relevant (i.e., distracting) schematic information below the activation threshold while conditional and more self-regulatory processing occurred. This type of processing situation reminds us that inhibition can vary from one situation to another, and sets the expectation that differing amounts of cognitive load may be experienced in relation to situations where more-or-less inhibition is required by the schematic activation inherent to the way the information is presented.

1.3.1 Scope of the investigation

It is important to note that the executive functions are developmentally distinct in terms of their relationship to cognitive development. Whereas most other WM functions display developmental increases sharply to about 8 years of age, the executive processes continue to develop to about 16 years of age (Gathercole, 1999, Karatekin, 2004; Kipp, 2005; Swanson, 1999), with inhibition itself viewed as reaching developmental maturity anywhere from 12 – 14 years of age (Becker, Isaac, & Hynd, 1987; Denckla, 1994, Harnishfeger, 1995; Wilson, Kipp, & Daniels, 2003). Thus, executive processing continues to present a significant developmental factor in learning right across most of the schooling years. For this reason, it is important to consider how demands made by executive processing might affect the learning experience for older, adolescent learners, as well as for younger learners. It is notable that, in both cases, a range of factors,
including inefficient instructional design, would place greater inhibitory demands upon available processing capacity.

Individual differences form one of the most important aspects of instructional design, especially in relation to mixed-ability classrooms. In this respect, the inhibitory function, as an aspect of executive WM processing, displays a wide range of individual differences in the ability to inhibit distracting information during on-task attentional focus (Harnishfeger & Bjorklund, 1994; Karatekin, 2004). However, research concerning executive control function and academic learning is at an early stage of understanding. Although some research has been conducted into executive control function with respect to written expression (Berninger et al., 1996; Hooper et al., 2002), mathematical problem solving (Barrouillet, Fayol & Lathuliere, 1997; Passolunghi, Cornoldi, & de Liberto, 1999) and specific areas of special needs learning (Gathercole, 1999; Pickering & Gathercole, 2004), to date no one has established a clear relationship between specific executive control functions, such as inhibition, and cognitive load in relation to mainstream classroom learning.

Indeed, Morris (1996) has suggested it is difficult to investigate specific executive control functions in relation to learning, because interrelations between the various functions make it difficult to examine the unique contribution each function might make to the learning. However, this difficulty is likely to reflect the fact that much of the existing research in the area of WM executive functioning has either been directed at domain-specific areas of learning (e.g., maths, science, or written expression), or been focused on learners with special needs. In addition, most WM research has tended to highlight ways in which problematic task-relevant processing creates a susceptibility to poor performance on a specific task. In contrast, relatively little research has looked at ways in which the ability to suppress irrelevant information might also contribute to poor learning at the more generalised level of classroom learning, and in relation to specific measures of inhibition. Meanwhile, both information processing theory (Goswami, 2004, Smith, 2004; Winne, 1995) and WM research (Engle, 2002; Corbetta et al., 1995; Gathercole & Pickering, 2000; Hopfinger, Buonocore, & Mangun, 2000; Vermunt, 1996) have posited the activation of relevant memory relating to incoming information, and the suppression of irrelevant memory that might also be activated by
the incoming information, as being required by the process of learning. Thus, both theory and research support the need to investigate inhibition as a particular area of educational research.

In an effort to build upon understandings gained from previous research in the area of WM executive control functions and learning, the focus of the present investigation is to establish whether or not individual differences in inhibitory ability correspond significantly to students’ experience of cognitive load. A secondary focus is to establish whether the relationship between inhibition and cognitive load has a significant effect on the achievement outcomes of the participating students.

The investigation rests upon an assumption that the instructional approaches of individual teachers do place differential cognitive demands on the processing capacities of individual students. This assumption is based on the expectation that the way individual teachers encode, or organise instructional information involves various amounts of processing ambiguity (i.e., individual differences in teachers’ instructional organisation). This is a fairly linear assumption, involving the differential encoding of information by teachers, selective inhibition from students, and individual experiences of cognitive load. However, as this is a pilot investigation, it is felt that this assumption provides a necessary initial expectation relating to the moderating influence of inhibition on cognitive load. To test this expectation, the investigation addresses inhibition in relation to different instructional approaches, as experienced in terms of cognitive load.

As a caveat, it is also acknowledged that the investigation is inherently comprehensive, and thus, by its very scope, may provoke deliberations concerning what is relevant for the reader at times. However, in order to provide overall clarity for the thesis, the reader is reminded that each segment and portion of the investigation represents an effort to bring together theory and practice. Thus, if the conceptual framework appears to contain irrelevant material at times, the reader is asked to reconcile this by referring back to the underlying relationship between cognitive load as a theory, and cognitive inhibition as an aspect of the processing required for classroom learning. It is this relationship that forms the common denominator for the investigation.
1.4 Research questions and related hypotheses

The investigation addresses the relationships occurring between general WM capacity for a cohort of Year-8 students, inhibitory function for these students, and cognitive load ratings assigned by the students to various teachers they had in common, with specific achievement outcomes (as determined by the teachers) being used as an indication of how the instruction has affected actual student learning. Posner and Fan (2008) have noted that the processing of ambiguous information requires the need for increased attentional resources, in particular inhibition. Therefore, the basic proposition for this investigation is that differences in student inhibitory ability will translate into corresponding differences in mental effort. Additionally, it is proposed that these differences will interact with received instruction to produce systematic differences in the way that students assign mental effort to the four teachers, and that these assignation differences will correspond to differences in the instructional organisation of the teachers. Finally, it is expected that the differences in student inhibitory ability will interact with the teachers’ instructional encoding to produce achievement outcomes that correspond to the distribution of both inhibition and mental effort amongst the students. Five specific questions appear to follow from these propositions.

1. Do inhibitory differences, as established by recognised measures of inhibition, exist within a normally distributed student population?
2. Is there a generalised relationship between students’ WM function and their academic achievement outcomes?
3. Is there a specific relationship between students’ inhibitory differences and their academic outcomes?
4. Assuming such inhibitory differences do exist, do they result in students experiencing different amounts of cognitive load, as measured by the students’ cognitive load ratings?
5. Are learning outcomes for students differentially influenced by their inhibitory ability and the way this ability affects the amount of cognitive load they experience under the different teachers?

Based upon these questions, and in light of the general expectation underpinning this investigation - that not only do individual differences for inhibition exist but also that
these differences interact with instructional ambiguity in a predictable manner - seven specific hypotheses are advanced (see chapter 5 for a fuller discussion and breakdown of these hypotheses):

\( H_1 \): That a significant, positive relationship exists between WM function and student achievement outcomes.

\( H_2 \): That a significant generalised relationship exists between student inhibitory ability (CI scores) and student cognitive load (CL ratings for the instruction they receive).

\( H_3 \): That a significant interaction exists between the students’ inhibitory ability (CI), cognitive load ratings (CL), and the way the teachers encode instruction for relevant vs. irrelevant information.

\( H_4 \): That a significant interaction exists between the students’ inhibitory ability (CI), cognitive load ratings (CL), and the way the teachers ask questions in a way that gives irrelevant or distracting semantic cues to the students.

\( H_5 \): That a significant interaction exists between the students’ inhibitory ability (CI), cognitive load ratings (CL), and the degree to which the teachers use words with multiple referents available.

\( H_6 \): That a significant interaction exists between the students’ inhibitory ability (CI), cognitive load ratings (CL), and the degree to which the teachers make only weak semantic associations to technical or jargon words.

\( H_7 \): That a significant interaction exists between student inhibitory ability (CI), cognitive load (CL), and achievement outcomes (ACHIEVE) for the students.

Table 1 presents an overview of how the various study factors are understood to interact. Individual student processing capacity can interact with different levels of cognitive inhibition, and can also vary between cognitive load ratings for the various teachers. In turn, individual student profiles for these processing-related measures can then also vary in relation to achievement outcomes, affording some ability to map the processing measures against actual learning outcomes.
Table 1.1 Factorial overview of study relationships

<table>
<thead>
<tr>
<th>Student</th>
<th>WM Capacity</th>
<th>Inhibitory Function</th>
<th>Cognitive Load Rating</th>
<th>Achievement Marks</th>
</tr>
</thead>
<tbody>
<tr>
<td>“1”</td>
<td>(measured in terms of individual processing differences)</td>
<td>More Able</td>
<td>Teacher 1</td>
<td>Teacher 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Less Able</td>
<td>Teacher 2</td>
<td>Teacher 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Teacher 3</td>
<td>Teacher 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Teacher 4</td>
<td>Teacher 4</td>
</tr>
</tbody>
</table>

1.5 Methodology and nature of the data collected

Chapter 5 provides details of the methodology adopted for the investigation. In overview, there were four key data-collection stages:

1. Measuring WM and inhibitory function for 114 mixed ability Year-8 (8th grade) students, all of whom received instruction under four participating teachers;
2. Measuring the teachers’ use of four (4) instructional elements relating to instructional organisation;
3. Having the students rate the teachers in terms of the mental effort they experienced while performing sixteen (16) different learning tasks for each teacher; and
4. Having the teachers assign achievement marks to the students for each of the 16 learning tasks.

The first and third of these stages will produce evidence to enable investigation about whether or not there is a correspondence between inhibitory ability and cognitive load for the students. The second stage allows for investigation of the extent to which the participating teachers are encoding instructional information in a similar fashion. The fourth stage provides the data necessary to assess whether or not the students’ inhibitory function is exerting a discernible effect upon their achievement outcomes. Statistical analyses will be performed to determine if any of these relationships are significant.
Student participants consisted of a mixed-ability group of year 8 students ($n = 114$, mean age = 13.83 years, SD = .40 years). This sample was viewed as developmentally appropriate, and the size of the group seemed adequate in light of a prospective power analysis (Tabachnick & Fidell, 2007). Assuming one independent factor (inhibitory function), and three dependent factors (mental effort, instructional organisation, and achievement outcomes), and nominating an effect size of 0.4, with alpha at 0.05 and a power level of 0.80, the power analysis had indicated that a minimum sample size of 96 participants were required for the study. Participating students were tested initially in terms of a variety of WM capabilities, including inhibition, and then academically tested across the 16 learning activities during the course of their Year-8 studies.

Four teachers (1 female, 3 male) who taught these students also participated in the investigation. Although representing a sample of convenience, the teachers presented with a variety of background experiences and instructional approaches, and included a moderately wide range of teaching experience (mean years teaching = 8.5, SD = 5.20 yrs, range = 2 to 14 years). Classroom observations were conducted on the teachers’ use of four different instructional elements, in conjunction with each of the 16 learning activities.

Ethics approval for the research was obtained from the relevant authorities (Southern Cross University Ethics Committee approval: ECN-03-157; NSW Department of Education and Training approval: SERAP 04.44).

1.6 Limitations

Cognitive learning theory is a large field, with many concerns and models to deal with. For the purposes of the present investigation, the emphasis is on how the specific executive function relating to inhibitory control relates to the experience of cognitive load within a mainstream classroom environment. Thus, it is important to distinguish between the broader theory of cognitive learning that forms the framework for the study, and the specific hypotheses being postulated here. A model of the postulated study relationships is presented in chapter 5 of the thesis, but it is to be noted that this model is designed to
represent the hypothesised influence for inhibition in relation to cognitive load only. The current thesis is directed at investigating this hypothesised influence, and does not seek to identify or establish a generalised theory or model of cognition in relation to. Thus, not all areas of cognitive learning theory will be applied to this investigation at the same level of analysis and interpretation.

For example, models of attention comprise an important element in the literature on information processing. However, limited use of these models is made in this investigation, principally because most of these models do not directly stipulate the importance of inhibition in relation to learning. Models of attention are discussed in chapter 3 because they do inform the conceptual framework for the investigation, but they are not a primary focus for the research questions and hypotheses.

Likewise, the concepts of metacognition and self-regulated learning, although related conceptually to executive function, are also considered to lie outside the main focus of the investigation, which concerns the neuro-cognitive functions associated with processing information in relation to received instruction. This is because issues of self-awareness and motivation, which are of significance in the literature on metacognition and self-regulated learning, cannot be measured as directly as can the executive functions that relate to WM.

Neither is the investigation overly concerned with the role of social factors (e.g., SES, ethnicity). These factors might well influence the relationships under investigation to some degree. Yet the quasi-experimental nature of the present investigation allows little capacity to control selectively for such large scale variables, and therefore the investigation remains focused on the more fine-grained sources of individual differences associated with the executive functions of WM.

Another limitation for the study is that it does not include the influence of learning style as a factor in the achievement outcomes for students. Learning style is a term used to refer to the notion that individual students process information according to a “natural processing style” (International Learning Styles Network, 2008), and that this processing style best determines the type of instructional approach the student is able to learn from.
Learning style thus represents the idea that various and different perceptual modalities exist for students, for example visual, linguistic, auditory, and kinaesthetic (Biggs, 1987), or diverger, assimilator, converger, and accommodator (Kolb, 1985).

Importantly, the notion that teaching to a student’s learning style can enhance learning outcomes has often been touted as a valid and reliable instructional approach (Dunn, & Griggs, 2003), and the influence of learning style as an important influence on learning outcomes tends to be widely promoted by educators (Biggs, 2001; Hattie, Biggs & Purdie, 1996). However, both the notion and efficacy of learning style have been highly contested in the literature (Pashler, McDaniel, Rohrer, & Bjork, 2008; Willingham, 2005), and comparisons between the influence of learning style and other influences, such as metacognitive instructional approaches, suggest that learning style is not nearly as influential on student outcomes as has been commonly believed (Marzano, 1998).

In addition, the influence of learning style is generally viewed in relatively categorical terms, that is, as an influence that affects the way specific groups of individuals process information, similar to the notion of a stable trait (Coffield, Moseley, Hall, & Ecclestone, 2004). In contrast to this, the focus for the current study is upon individual differences for cognitive inhibition, a much more specific and less generalised influence that has to do with the context-specific and situated nature of information processing. Because of this, and in light of the aforementioned issues relating to the efficacy of learning style, the influence of learning style has not been incorporated into the current study.

In general, these limitations are not considered to be major. The main importance of the investigation lies in the fact that it will help to determine whether inhibition can be viewed as a causal mechanism for the theory of cognitive load. However, in addition to this, it is also expected to help delineate the types of problems students with poorer inhibitory abilities experience with respect to mental effort, whether inhibitory ability responds in a systematic way to instructional encoding, and whether or not inhibitory ability moderates achievement to a significant degree. Therefore, while exploration of the role and influence of a wider range of considerations - such as self-awareness, motivation and social factors - might seem desirable, the scope of the present investigation, piloting as it does an investigation into the relationship between cognitive
inhibition and cognitive load, does seem sufficient to the intent of the thesis within the context of our current understanding of cognitive learning.

1.7 Important definitions

Definitions adopted by researchers often vary, so key terms are defined here in order to clarify positions taken in the current investigation. These definitions are formulated in a way that draws attention to underlying assumptions. Core constructs are addressed much more fully in chapters 2 and 3. Key terms are:

- **attention** – The focused allocation of cognitive resources upon a particular stimulus or set of stimuli. In general, learning can only accommodate what the learner has attended to. Attention is commonly differentiated as selective attention and divided attention, where selective attention refers to the ability to focus on certain stimuli or tasks while simultaneously ignoring others, and divided attention refers to the ability to attend to two or more tasks simultaneously.

- **automaticity** – An aspect of skill acquisition in which the performance of a cognitive skill becomes more or less automatic in its execution. Automaticity stems from *schema theory*, and forms an important part of *cognitive load theory*. Automatised cognitive procedures require much less WM resources than non-automatised procedures.

- **cognitive inhibition** – This term is used by cognitive and neuro-psychologists to refer to the suppression of distracting or non-relevant information during on-task cognitive engagement. The terms *inhibition* and *inhibitory function* (in places designated simply, as “CI”) refer more broadly in this investigation to the inhibitory function associated with WM and conceptualised as a functional connection between items of information where, when two or more items are competing for attentional focus, one of the items needs to be suppressed.

- **cognitive learning theory** – Associated with Bruner (1990), cognitive learning theory is concerned with how the learner manipulates both new and familiar information in order to make meaning out of the information. Cognitive learning theory focuses on how the cognitive functions involved in information processing develop in conjunction with improved processing strategies to allow progressive improvement in the ability to process information efficiently.
• **cognitive load theory** – A theory proposed by John Sweller and associates, which focuses on the role of working memory capacity limitations in instructional design. This theory is used in the present research as part of the rationale linking instructional design to the cognitive functions of the working memory system.

• **controlled attention (see attention)** – The ability, as used in perception and cognition, to focus the allocation of cognitive resources in order to process information from a particular stimulus or task-relevant set of stimuli while ignoring extraneous or task-irrelevant stimuli. Controlled attention requires the active suppression of task-irrelevant information in order to screen out competing stimuli.

• **dependent variables for the study** – A dependent variable is one that is influenced by the action of the independent variable. In the current study, there are two main dependent variables: cognitive load and overall academic achievement.

• **domain specificity** – Refers to information that is specific to a particular situation or content area (e.g., maths, science), as opposed to information that can be generalised across different situations or content areas (i.e., language, general problem-solving ability).

• **error detection** – To evaluate research findings statistically, we need to know how much of the findings are due to error. The level at which we set our expectation for a particular type of error, known as the alpha level, determines how likely it is that we will be able to accurately evaluate the findings. In the current study, statistical analyses used an alpha level of .05, meaning that there was less than a 5% probability that significant statistical findings had occurred by chance.

• **equilibration** – Piaget’s idea that cognitive development is driven by the desire to balance existing knowledge (in the form of cognitive schemata) with new information coming from the external environment. Piaget viewed equilibration as occurring due to two cognitive processes: accommodation and assimilation.

• **executive control functions** – As used here, executive control functions refer to the higher-level working memory operations essential for the production of goal-oriented cognitions and behaviours. Executive control functions manipulate information for the purpose of dealing with the complex, surprising, time-sequenced, and sometimes conflicting situational characteristics of information processing. Cognitive processes involved here include working memory, goal
representation (a form of representational holding), planning, response monitoring, and error detection.

- **independent variable for the study** – This is the variable as defined by the researcher to be influencing (rather than influenced by) the research situation. The independent variable of interest for this study is cognitive inhibition. Thus, the expectation is that tasks requiring greater cognitive inhibition will result in corresponding changes in the variables conceived as dependent on this factor (in particular cognitive load, but also academic achievement).

- **information processing theory** – This theory uses a computer metaphor to assert that the human brain processes information in stages and according to discrete processing functions. Information processing theory is an important theoretical approach with respect to the cognitive aspects of learning. It describes the structures, processes, and limitations of the individual learner in terms of the amount, accuracy and recall of information.

- **instructional design** – That area of teaching concerned with giving structure and meaning to the design of classroom practice. Various approaches to instructional design exist (behavioural, cognitive, phenomenological, social-cognitive), yet a common emphasis is upon developing a systematic approach to designing instructional strategies that direct the learner’s focus to the object of the learning. This investigation addresses cognitive approaches to instructional design.

- **instructional elements** – The term “instructional elements” for the study refers to those aspects of the learning situation that derive from the classroom teacher, including the way they organise task-related information and how they encode (organise) instructional information.

- **learning activities** – For the current study, this term simply means a classroom lesson, and is used to refer to the sixteen (16) classroom sessions that were observed for the study, and for which each participating student reported a measure of cognitive load for the study.

- **overall academic achievement** – This term is used in the study to refer to the overall achievement mark received by each participating student from their classroom teacher.

- **pedagogy** – Sometimes referred to as “the art and science of teaching”, the word derives from two Greek terms, *pedais* – to travel by foot, and *gogue* – to lead,
hold under authority, or rule. The common translation of pedagogue is “one who leads children”, and pedagogy has come to mean the act of teaching as a professional endeavour. Cognitive pedagogies are those approaches to teaching that rely on cognitive models of learning.

- **priming** – In information processing theory, anything that activates memorial (schematic) information and makes it accessible for processing. Positive priming can facilitate efficient processing in that it activates salient, task-relevant information, thus increasing *automaticity* for the processing. Negative priming can hinder efficient processing in that it activates irrelevant information, thus necessitating greater use of inhibition.

- **redundancy effect** – In relation to cognitive load theory, when information is presented in overlapping formats (a text, explanatory notes, a glossary, etc.), and much of the information is repetitive. The redundancy effect can also occur when one form of instruction (e.g., verbal instruction) is reinforced by simultaneously providing the same information in another format (e.g., written notes) making the information redundant. Redundancy is considered harmful to learning because it requires the learner to hold more information in short-term memory than is necessary.

- **representational holding** – This refers to the amount of information that is held in short-term memory during a learning task. Different instructional strategies can require different amounts of representational holding, making this an important concept to understand in relation to the current investigation.

- **response monitoring** – Refers to the measures by which a specified response (e.g., saying “yes” or “no”) is evaluated. In the current study, responses to incongruent Flanker tasks were monitored in terms of student participants pressing buttons on a “response box”.

- **schema theory** – A theory concerning how information is organised in long-term memory (LTM). Schema theory proposes that categorical rules or scripts are used to organise the information in LTM, so that the information can be assigned conceptual meaning, and then accessed by associating new information to its relevant concept structure. For example, we all have a schema for the concept of “dog”, whereby we might think of information concerning something warm, furry, and perhaps with big teeth as relating to that animal. Schemas influence
memory in a variety of ways, but they are particularly important to attentional processing, where, according to Cohen (1993) they are used to guide attention.

- **schemata** – Relating to schema theory, schemata are hypothesised cognitive structures that organise knowledge, direct perception and attention, and guide information recall according to principles of association (the contingent pairing together of information items). Schemata serve as the scaffolding for conceptual organisation and are therefore important to the notion of automaticity, where they allow information to be “chunked” for more efficient information processing.

- **split attention effect** – In relation to cognitive load theory, an information processing effect that occurs when learners are required to attend to two distinct sources of information during a learning task, causing them to simultaneously integrate multiple sources of information. Split-attention is viewed as imposing high cognitive demands on the limited capacity working memory system.

- **working memory (WM)** – A term commonly used in cognitive and neuropsychology to refer to that part of the information processing system at which the temporary storage and manipulation of active information occurs. WM is characterised by limited capacity, temporary information storage, and fast processing.

### 1.8 Organisation of the investigation

The investigation is organised into seven chapters. This first chapter introduces the investigation and its associated themes. The purpose of this chapter has been to outline the larger picture of the investigation and orient the reader to the basic concepts and processes involved, including WM, inhibition, and cognitive load. In this chapter a primary thesis has been put forward which alleges that inhibitory ability serves to moderate the amount of cognitive load students experience in relation to classroom learning. A secondary thesis was also put forward in this chapter, suggesting that the moderating effect of inhibition also has an effect on the learning outcomes achieved by individual students.

Chapters two and three will support these thesis ideas by reviewing the existing literature relating to the theoretical ideas and research findings they involve. The relevant
literature was covered in two chapters because the scope of the thesis being put forward is quite broad, and thus the review of relevant literature needed to combine quite a few different areas of knowledge for the overall review. However, the segmentation of materials into two different chapters also serves the purpose of delineating both the broad theoretical framework involved in the thesis (chapter 2) and also the more specific understanding of how this framework can be related to inhibition, cognitive load and instructional design (chapter 3).

Chapter four then introduces the theoretical model which attempts to depict the moderation effect posited for inhibition in relation to cognitive load. This model, referred to as the inhibition X cognitive load model of attentional processing, forms the basis upon which the hypotheses relating to the investigation were constructed. Thus, chapter four provides the theoretical rationale by which the development of the thesis’ hypotheses and methodology were determined.

The final three chapters (5, 6, & 7) go on to describe how the proposed relationships between inhibition, cognitive load, and achievement were investigated, and what the outcomes of this investigation were. In this respect chapter five describes the methodology used to test the thesis ideas, a quasi-experimental approach that tried to capture authentic classroom information while also allowing for the gathering of data on specific theoretical constructs. Chapter five seeks to relate the hypotheses of the investigation to the specific sample, procedures, and instruments used to test the thesis ideas. Chapter six then details the information that resulted from the investigative methodology used in the investigation. Here the results are presented and collated in a way that systematically interrogates and interprets each hypothesis of the investigation. Finally, chapter seven seeks to discuss and summarise these results in a way that provides a meaningful overall interpretation of the investigation. This chapter links the theoretical ideas of the investigation (the thesis) to the results of the investigation, to provide overall discussion and insight concerning the theoretical and applied (classroom) levels of understanding for the thesis.

Chapter two will now begin reviewing the relevant literature, to provide an essential theoretical framework by which to understand the overall importance and
influence of cognitive learning theory, information processing theory, and schema theory. These are all considered essential to the investigation because they provide the larger framework within which the more specific executive functions relating to WM and attentional processing are positioned. Chapter three will then continue the literature review, and delineate the specific theories and research that represent the specific information processing elements of the investigation, including attentional processing, executive function, inhibition, cognitive load, and the concept of cognitive priming.
CHAPTER 2: REVIEW OF THE LITERATURE

How valuable is cognitive neuroscience to educational psychologists?...The eventual answer will probably be that it is very valuable indeed. The tools of cognitive neuroscience offer various possibilities to education, including the early diagnosis of special educational needs, the monitoring and comparison of the effects of different kinds of educational input on learning, and an increased understanding of individual differences in learning and the best ways to suit input to learner.

(Goswami, 2004, p.3).

2.0 Introduction

This literature review is divided into two different parts, as contained in chapters 2 and 3 of the thesis. Chapter 2 reviews the broad theoretical framework within which the thesis is located, while chapter 3 examines the more detailed aspects of this framework as they are particularly relevant to the thesis. Together, these two chapters provide an overall theoretical context for the study by reviewing the available literature in a number of key areas, as follows:

2.1: An overview of cognitive learning theory as applied information processing theory
2.2: A review of information processing theory
2.3: A review of schema theory
3.1: A review of the working memory (WM) system in relation to attentional processing
3.2: A review of cognitive inhibition in relation to classroom learning and teaching
3.3: A review of cognitive priming as an information processing phenomenon related to the inhibitory function
3.4: A review of cognitive load theory in relation to priming and inhibition
3.5: Executive summary of the overall literature review findings

In each of these areas the important theoretical principles are discussed as they apply to classroom learning and to the current study. Gaps in the available literature are highlighted, and a rationale presented concerning how the current study can contribute to
the field of education. The first part of this literature review (2.1, 2.1, & 2.3) examines the larger theoretical frameworks in which the thesis is located.

2.1 An overview of cognitive learning theory

Cognitive learning theory views instructional strategies as mental operations or principles, by which the problem-solving abilities of learners are increased, domain-specific performance is enhanced, or the encoding and retrieval of memory is improved (Alexander & Jetton, 2003; Bjorklund & Buchannan, 1989). This perspective is appropriate and useful to the thesis because it suggests that the content of teaching and learning is pedagogically inseparable from the cognitive and neurological processes involved in teaching and learning. Forging a broad based, trans-domain, “best practice” pedagogy, therefore, requires that we consider the neuro-cognitive elements of teaching, because these elements are critical to understanding how students are best enabled to process information that is diverse, multi-layered, and often conflicting. This discussion will begin by summarising the core understandings of cognitive learning theory. It will then review the major approaches to instructional design that have been derived from cognitive learning theory.

2.1.1 Cognitive approaches to classroom instruction

In recent times an educational industry has developed around the notion of “brain-based” learning, that is, learning which is scaffolded via the application of cognitive and neuropsychological knowledge (Katzir & Paré-Blagoev, 2006; Lackney, 2004). Examples of this include efforts to match instructional strategies to student learning styles (Clemons, 2004; Tait & Entwistle, 1998), instructional approaches designed to focus hemispheric processing (Sprenger, 2002), and the application of mnemonic strategies to help overcome the capacity limitations of the human information processing system (Carney & Levin, 2002). Such ideas, representing as they do attempts to apply advances in cognitive and neuropsychological research to an educational context, continue to gain widespread acceptance within educational circles, and in many instances form the basis upon which to design classroom instruction (Stevens & Goldberg, 2001). Often these ideas are over-simplified and uncritically applied to the teaching and learning situation (Bruer, 2002; Pinker, 2002; Wolfe & Brandt, 1998). Yet
cognitive learning theory is increasingly being linked to evidence concerning specific cognitive and neurological functions, as educators seek to clarify the details of learning and teaching across a variety of domain-specific and domain-general areas (Berninger & Cowell, 1985; Byrnes & Fox, 1998; Gathercole, 1999; Hegarty, Mayer & Green, 1992; Kintsch & Greeno, 1985; Pickering & Gathercole, 2004).

Research concerning the working memory (WM) system provides much of this evidence, and therefore represents an area of inquiry crucial to the understanding of learning and teaching from a cognitive perspective. As noted in chapter 2 of the thesis, WM is a cognitive construct, generally viewed as functioning in a domain-general manner (i.e., involved in learning across all curriculum areas), and widely used to account for the limited processing capacity of the human information processing system. The relationship between WM and classroom learning is well established, and has found wide applicability within the education system (Byrnes, 2001; Byrnes & Fox, 1998; Goswami, 2004; Pickering & Gathercole, 2004; Schmid, Tirsch, & Scherb, 2002; Smith, 2004; Sweller, van Merrienboer, & Paas, 1998; Vermunt & Verloop, 1999). A detailed review of WM will be undertaken in section 3.2 of the thesis, but at this point it is important to note that cognitive learning theory is based primarily on an understanding of how to apply WM function to classroom learning situations, and that a core feature of WM function is its limited processing capacity.

At the heart of this applied understanding is the desire to improve instructional design, a term broadly used to refer to that field of education concerned with how to think about and make sense of the programs and approaches used to teach curriculum content (cf. Joyce, Weil, & Calhoun, 2000). Cognitive approaches to instructional design generally involve using the mental operations or principles by which problem-solving abilities are increased (Kosslyn & Koenig, 1992), domain-specific performance is enhanced (Byrnes, 2001), or the encoding and retrieval of memory is improved (Pickering & Gathercole, 2004). The goal of cognitive learning theory is, therefore, to effectively apply the principles of cognitive processing to the way curriculum content is organised and presented, in order to maximise learning.

2.1.2 Cognitive approaches to instructional design
Although early cognitive views of learning tended to emphasise the acquisition of knowledge as the focus for instructional strategies (Anderson, Reder, & Simon, 1996), more recent approaches have tended to stress knowledge construction (Greeno, Collins, & Resnick, 1996; Mayer, 1996). Important to the thesis, however, is that all cognitive approaches to instructional design have generally focused on ways to increase or extend the attentional focus of the learner. For example, the seminal work of Benjamin Bloom (1956) was foundational to informing educational designers concerning the importance of intentionally classifying instructional objectives across the cognitive, affective and psychomotor domains of activity. Bloom’s taxonomy of mental operations thus set the stage for melding ideas about cognitive structure and function into learning outcomes that require different types of task-related, applied thinking (see Anderson & Krathwohl, 2001, for a revised taxonomy of applied thinking). Bloom’s taxonomy describes how the use of task-relevant information is to be systematically defined, organised, evaluated, and applied.

Similarly, Ausubel’s (1978) *Meaningful Receptive Learning Theory* involves the use of hierarchically-ordered categories of “meaningful learning”. The notion of meaningful learning posits a cognitive process by which new information is continually attached to, and organised by, the learner’s existing hierarchy of knowledge. Ausubel’s understanding of learning emphasises instructional strategies that organise and represent task-relevant content as a means of controlling how the learner structures knowledge. Thus, meaningful learning theory seeks to direct attention to task-relevant information as a primary principle of instructional design.

Gagné’s (1985) hierarchy of learning types has been used to identify five distinct domains of task-relevant “learned capability” (motor skills, verbal information, intellectual skills, cognitive strategies, and attitudes). These are defined as domain-specific areas within which learning occurs. Gagné accentuated developmentally efficient problem-solving within each of these domains as the hallmark of on-task procedural thinking, and his hierarchy consequently delivers both developmental and evaluative structures for instructional design. An important assumption of Gagné’s hierarchy is that instruction should be varied according to the type of content being learned. This emphasises the role of prior knowledge in learning-related processing (Gagné & Glaser, 1987), and provides a clear link between instructional design and
schema theory. In particular, Gagné’s use of domain-specific cognitive strategies recognises that schema activation is necessary to the effective processing of information, and stipulates that teachers should develop distinct strategies for relating new learning content to existing knowledge.

Gagné’s idea of schematic activation highlights one of the key conceptual constructs involved in cognitive learning theory, the notion of mental *schemata*, or “knowledge structures” as the basis for learning (cf. Schank & Abelson, 1977). This notion also provides the basis for *Instructional Transaction Theory* (Merrill, Jones, & Zhongmin Li, 1992) and Presseisen’s (2001) model of essential, complex and metacognitive thinking skills, both of which have emerged from cognitive learning theory more recently. The importance of both theoretical orientations is that they have been instrumental in shifting the focus of cognitive pedagogies to *constructivism*, a philosophy of learning based on the notion that individuals ‘construct’ a meaningful representation of learning by cognitively manipulating information into a personal understanding of the knowledge involved (cf. Duffy & Cunningham, 1996; Jonassen & Carr, 2000; Jonassen & Reeves, 1996; Phillips, 2000; von Glaserfeld, 1997).

Presseisen, in particular, has attempted to promote constructivist pedagogy by providing a taxonomy of “essential thinking skills” for the purpose of developing shared understandings between teachers and students. These essential skills concern how to qualify curriculum content, how to classify the content, how to recognise content relationships, how to transform (generalise) curriculum content, and how to assess or evaluate it. This is reminiscent of Bloom’s taxonomy, and Presseisen does present these understandings in the form of a progressive taxonomy, viewed as providing a common basis for the construction of content-relevant knowledge. Although Presseisen herself has emphasised that understanding should be developed within a collaborative or distributed context, these thinking skills are directed at focusing attention on how to meaningfully construct task-relevant knowledge at the personal level. This is a highly cognitive and rational approach to constructivism, with a consistent focus on how to understand and apply task-relevant information.

Important to the thesis, the overall focus for these instructional design approaches is on how to organise and activate task-relevant schemata, and how to
develop the requisite processing skills to assist this. The need to inhibit task-irrelevant schemata does not appear prominent as a design principle, nor do these approaches seem to establish explicit inhibitory or priming strategies in relation to schema activation. This supports the thesis position that a gap exists concerning how inhibition affects the teaching/learning process relative to instructional design. A closer look at how cognitive learning theory has been applied to classroom instruction seems therefore to be in order.

2.1.3 Applications of cognitive learning theory to classroom practice

Various studies have investigated how the ideas and principles of cognitive learning theory might be applied at the classroom level of teaching and learning. For example, Pichert and Anderson (1977) used perspective taking to show that, by directing attention to different perspectives in relation to a static set of information, student processing of the information could be significantly biased in terms of how the information was recalled. They interpreted their findings as an indication of how important cognitive schemata are in guiding the organisation of information. Perspective taking represents a type of information priming, and as such directs the learner’s attention to specific conceptual associations in terms of how the information is to be interpreted. This research highlights the relationship between schemata and learning-related processing, and suggests the importance of conceptual priming.

From a different perspective Gilovich (1991) used attentional focus to assess processing logic. He found that task-relevant information must be considered ‘reasonable’ for an individual to accept it as valid. Gilovich concluded that the logic of information encoding is determined largely by the extent to which new information can be linked to what the learner already knows about the topic, that is, to the degree of “schematic congruency” that exists for attentional information in relation to existing knowledge. This implies that an implicit expectation exists for the way information is processed, based on the way in which the schematic elements of the information are linked logically in relation to prior knowledge. The impression is that something like executive inhibition is required for processing information that does not meet the logical requirements of schematic congruency.
In a similar investigation, Holland, Holyoak, Nisbett, and Thagard, (1986) applied the notion of conceptual elaboration to explain the process of abstract generalisation. They describe four types of inductive rules for representing an information generalisation process: *specialisation rules* (working from the abstract to specific instances), *unusualness rules* (nominating conditional specifications for unexpected or irregular inferences), the *rule of large numbers* (assuming rules that apply effectively to a sample of ideas or beliefs will apply to all ideas of that nature), and *regulation rules* (rules that regulate inductive parameters, e.g., "If you want to do X, then you must first do Y", should be followed by, "If you do not do Y, then you cannot do X").

Holland and his colleagues have suggested that by using these rule-based processes, informational similarities and differences can be identified, and information linkages then made to more general structures, that is, the rule-based processes can be used to form analogies and metaphors, important to transfer of learning (this is similar to Preissen’s transforming skill category, but also cf. Ortony, 1980). One interpretation of Holland et al.’s rule-based approach is that priming is being used to encode instruction for efficient processing because it increases the pre-attentional processing of specific, similar informational features (i.e., it creates schematic similarity) for the task-relevant information to be learned. The Holland et al. study can thus be used to example the importance of positive priming, a type of priming that can lower the amount of inhibitory function required (cf. Chi, Glaser, & Rees, 1982; Stanovich, 1990). Generalisation may work best when an implicit priming function is embedded within the instructional processing framework, targeting the processing of schematic similarity as the basis for analogical transfer.

Adams (1990) investigated the role of task-relevant attention in terms of how the reader translates printed words into their phonological equivalents before translating them to words. He noted that during the decoding process, task-relevant attention shifted from print to sound, and only then to recognizable words. Once the print to sound translation occurs, the reader constructs a surface-level representation of the syntactic (structural) and semantic (meaningful) aspects of the written message. According to Adams, it is this surface-level representation that is deposited in working memory, where it is analysed by appropriate information processing functions. Although Adams
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(1990) does not discuss the role of inhibition in phonological encoding directly, his analysis represents a high cognitive load processing situation, an aspect of cognitive processing viewed as connected to the inhibitory function.

A more recent study by Laufer et al. (2008) may illustrate this relationship more clearly. They used functional magnetic resonance imaging (fMRI) to support the idea that a type of phonological working memory is involved with the adaptive processing of speech. Specifically, they argue that a phonetic-based inhibitory system is responsible for adapting the pre and post auditory attentional processing of perceived speech deviations in relation to auditory semantics, and that speech-salient sounds require more cognitive (post-attentional) processing. Laufer et al. associate this system with the anterior cingulate cortex, and, importantly, suggest that phonetic inhibition may require additional processing effort.

Vermunt (1996) addressed questions concerning how students perform metacognitive, cognitive, and affective learning functions in relation to self-directed learning. He implemented a phenomenographic (self-reflective) methodology to categorise how students conceptualise and understand the experience of learning. Vermunt concluded that the nexus between cognitive models of learning and instructional pedagogy involves, at least in part, the development of generalised principles that operate during the entire teaching/learning process. Vermunt (1996) has characterised these generalised principles in terms of instructional strategies that:

1. Direct attentional focus to relevant learning and thinking activities.
2. Incorporate the explicit teaching of domain-specific thinking strategies.
3. Intentionally develop students’ mental models of learning.
4. Promote generalised transfer of learning.

According to Vermunt (1996), the essence of generalising is to use instructional approaches that teach explicit skills and information, and then use this information to build metacognitive understanding and transfer of learning. In this model, attention is explicitly directed to congruent, task-relevant aspects of the learning, in order to expand the role that controlled attention plays in classroom performance. Indeed, the underlying assumption seems to be that learning is a function of sustained, controlled attention onto the congruent, task-relevant features of information (as also advocated by Byrnes & Fox,
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1998; Jacoby, Craik, & Begg, 1979; Wittrock, 1986). However it also to be noted that for each of Vermunt’s steps (and especially steps 3 & 4), generalisation cannot be accomplished without proper schematic identification and activation. Mental modelling requires the use of conceptual understanding, which, in turn, depends on schematic integrity and logical processing. Transfer is characterised by the trans-domain applicability of information. Yet transfer cannot be accomplished without the identification of, and priming for, congruent, task-relevant information, in order to achieve a new identification for information that is no longer domain-specific. However, the process of information identification also requires the complementary inhibition of task-irrelevant information. Thus, the need to account for an inhibitory effect remains unclarified by this instructional approach; requiring further investigation of the specific influence inhibition may have on learning.

2.1.4 Position of the thesis in relation to cognitive learning theory

Broadly speaking, the main focus for cognitive learning theory is how to selectively encode for task-relevant attentional focus, in order to control the type of learning outcome that occurs. However, the idea of selectively attending to task-relevant information implies the need to also suppress or inhibit irrelevant information, so as to not be distracted from the attentional goal. Although it is accepted that most cognitive instructional approaches also acknowledge the importance of being able to inhibit distracting or task-irrelevant information during learning, this appears to be a fairly implicit assumption. The idea seems to be that if the instruction is designed to focus on task-relevant processing, then the suppression of irrelevant information will occur automatically.

In contrast to this, the current thesis emphasises specifically designing to the distinction between task-relevant and task-irrelevant processing. This distinction is supported by cognitive and neuropsychological evidence, which suggests that attentional processing can be viewed as the result of two complimentary processing mechanisms related to executive WM function: Maintaining selective focus on task-relevant information (Baddeley, 2001; Engle, 2002; Milliken, Joordens, Merikle & Seiffert, 1998; Pashler, 1997; Ronit, Faust, & Zivotofsky, 2008; Stadler & Hogan, 1996); and inhibiting distractions from task-irrelevant information (Cohen, Botvinick, & Carter,
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2000; De Young, 2007; May, Kane & Hasher, 1995; Passolunghi, Cornoldi & De Liberto, 1999; Wentura, 1999). The thesis is thus positioned within the current brain-based endeavours of cognitive learning theory, which attempt to connect instructional design to discrete brain areas and particular cognitive functions.

This position also involves matters of pedagogy. Educational pedagogy has traditionally emphasised the need for instruction to convey a large amount of information efficiently, yet pedagogical design seems to have failed to model this process sufficiently (Demetriou et al., 2002; Goswami, 2004; Brody, 1997; Byrnes, 2001; Byrnes & Fox, 1998; Montague & Warger, 1997; Talbert & McLaughlin, 1993). Indeed, Byrnes and Fox (1998), along with Goswami (2004), Sweller (1998), and Smith (2004), all assert that findings from cognitive and neuropsychological research have not transferred to classroom teaching and learning very well. In line with Gathercole (1999), and Goswami (2004), Byrnes and Fox (1998) have also asserted that the role of inhibition as a specific factor in learning is not well understood at present, and therefore requires particular investigation. These claims are important to the thesis because they support the need for ongoing research into the cognitive and neuropsychological aspects of teaching and learning as an area of inquiry, and because they call attention to the need to better understand inhibition as a distinct information processing function related to instructional design. A key objective of the thesis is to establish that the inhibitory function does influence the learning experience, particularly in relation to the amount of cognitive load, or “mental effort” associated with classroom learning.

Overall, cognitive learning theory is important to the thesis because it acknowledges that instructional design is concerned with the relationship between working memory (WM) and attentional focus. An important consideration is that memorial information (sensory, working memory and long-term memory) is limited with respect to attentional focus, as attention operates in conjunction with sensory inputs, the larger structures of archival knowledge, and the inhibition of irrelevant or distracting information. Important to the thesis is that the concept of processing constraint, and the means by which this limitation can be minimised, involves understanding how to design instruction in a way that accords with the inherent structures and processes of the WM system, including the inhibitory processing function.
2.2 Information processing theory

This part of the discussion will focus on the insights information processing theory provides concerning the role of specific cognitive processes involved in learning and teaching. Information processing theory outlines how the individual learner works within certain cognitive capabilities and limitations. It defines these capabilities and limitations by describing the structures and processes by which the learner processes information. Information processing theory also suggests how processing can be maximised by supportive instructional strategies that take into account these structures and processes, and which seek to account for their capabilities and limitations in terms of instructional scaffolding. Information processing theory is thus able to provide a broad theoretical framework for the thesis. It highlights the problems involved in learning-related information processing, and is also able to offer ‘best practice’ solutions to these problems in terms of instructional approaches that are informed by the theory.

2.2.1 Information processing theory as a model of mind

During the 1960’s and 1970’s the rapid development of computing technologies coincided with the developing field of cognitive psychology to forge a new conceptual model of human thinking, based on the manipulation of symbols as an information processing system (Klahr, 1992; Klahr & MacWhinney, 1998; Mayer, 1996; Rose, 1992). The information processing perspective thus represents a metaphor for the human mind. As such, it borrows heavily from developments in computing, and views learning primarily in terms of the discrete steps through which information is detected, recognised and encoded into memory (Kail & Bisanz, 1992; Lohman, 2000; Norman, 1965; Winne, 1995). Various models of information processing have been developed over the years, from general models which attempt to describe the human cognitive system as a whole (Atkinson & Shiffrin, 1968; Lockhart & Craik, 1990), to more specific models attempting to map precise learning steps that individuals use for problem solving or task-completion exercises (Clark & Chase, 1972; McClelland, Rumelhart, & Hinton, 1986; Rummelhart & Norman, 1978; Thornton, 1999).

All models of information processing seek to describe the processes and components of cognition that are universal to the way individuals learn, including the
notion that information is processed according to an orderly flow, that active or working memory is limited in processing capacity, creating a “bottleneck” effect for processing (Broadbent, 1970), and that the encoding and decoding of information from long-term memory is associated with schematic organisation (Anderson, 2000; Atkinson & Shiffrin, 1971; Derry, 1996; Gick & Holyok, 1983; Lutz, 2000; Marshall, 1995). Thus, as a theory, information processing presents a coherent overview of how the human mind processes and ‘learns’ information.

Information processing theory is generally described structurally, in terms of the cognitive architecture required to explain the processes and principles involved in the theory. This architecture is conceptualised in a form that attempts to explain how individuals perceive, manipulate, store, and retrieve information, in order to produce appropriate responses to the environment. Many educational psychologists represent this architecture as a series of interdependent processing stages or modules, with each stage or module representing a specific aspect of processing and learning (Krause, Bochner, & Duchesne, 2006; McInerney & McInerney, 2006; Woolfolk & Margetts, 2009; although cf. Byrnes, 2001; Byrnes & Fox, 1998). An overview of this architecture is shown in Figure 2.1, depicting the relationship between the environment, sensory memory, working memory, and permanent memory. Note that at each stage of processing, some type of mechanism is required to deal with extraneous, irrelevant, or distracting information, in order to allow for the coherent overall processing of information.

Figure 2.1 Overview of the information processing system, depicting the need for inhibition at each stage of processing.
2.2.2 Information processing and learning

Several aspects of information processing theory are connected to classroom learning, including the idea that meaningful processing derives from a coherent system of interconnected schemata (Anderson, 2000; Schank, & Abelson, 1977; Smith, & Medin, 1981), and that instructional strategies can be designed to either assist or detract from the effective use of prior knowledge in the processing of instructional information (Hong & O’Neil, 1998; Price & Driscoll, 1997). Importantly, information processing theory views learning as the product of a set of complex and interactive cognitive processes that manipulate information from the environment in relation to existing memorial knowledge, to achieve a deliberate outcome. Because of this, the interactions that occur between the learner and specific types of instructional approaches form an important aspect of individual differences with respect to differential learning outcomes. The scope of these differences encompasses variability in both cognitive development and individual ability, both of which have a bearing on the thesis.

2.2.2.1 Developmental Differences in Information Processing

In terms of cognitive development, the information processing model regards the child as an active thinker and constructor of progressive, personal knowledge systems (Halford, 2002; Klahr & MacWhinney, 1998). Piaget’s idea that cognitive-developmental schemata provide a mental framework for understanding and remembering information provided important pedagogical considerations in this direction, and has contributed to our understanding of how schema-driven learning strategies guide differences in novice versus expert knowledge (Chi, Glaser, & Farr, 1988), how problem-based learning occurs (Marshall, 1995; Mayer, 1982), how information is categorised (Bartlett, 1958; Mandler, 1984), and how memory retrieval works (Pascual-Leone, 2000; Smith & Medin, 1981; Sweller, 1994).

According to cognitive-developmental theorists, schemata change and develop along with cognitive growth, by adapting to the increasing complexity of mental activity as provided by external stimuli, and by internal organisational changes which forge progressively larger cognitive networks of information (Johnson, 2001; Karatekin, 2004;
This has led to an understanding of learning as occurring within a broad, cognitive-developmental framework (Gathercole, 1999; Pickering & Gathercole, 2004; Pressley & McCormick, 1995; Swanson, 1999), and highlights the importance of understanding age-appropriate cognitive processes when forming a theory of learning (Brainerd & Reyna, 1990; Ornstein, 1978; Pascual-Leone, 1987).

Cognitive learning theory uses this developmental framework to examine how cognitive-developmental functions contribute to individual differences across a variety of learning outcomes (Bruner, 1990; Bruning, Schraw, & Ronning, 1999), including how specific information processing functions direct the learning process along a developmental continuum (Kosslyn & Koenig, 1992; Tuholski, Engle, & Baylis, 2001; Smith, 2004; Wellman & Gelman, 1992). In this respect, Pascual-Leone (1987; 2000) proffered a cognitive-developmental formula for measuring developmental differences in processing capacity, and Gathercole (1999) has noted explicitly how developmental differences can be applied to educational outcomes. In a similar vein, Fry and Hale have (1996) described how developmental differences in working memory capacity can be used to account for increases in age-related fluid intelligence. The relationship between development and information processing forms an important understanding to the way cognition is able to respond to instructional design in a progressively complex manner.

2.2.2.2 Information processing and individual differences

Another important aspect of information processing theory in relation to learning involves individual differences in processing ability. Indeed, a clear strength of information processing theory is that it has been successful in offering precise accounts of individual learning differences (Byrnes, 2001; Engle, Kane, & Tuholski, 1999; Myake, 2001). As well, individual differences in working memory (WM) capacity tend to be highly correlated with several common indices of efficient learning, including reading comprehension, reading speed, and overall reasoning skills (Conway et al. 2005; Engle, 2002). In this respect Gathercole and Pickering (2000) used an individual differences approach to link differences in WM function to the range of national curriculum outcomes that occurred for 83 stage-1 (first grade) students in the United Kingdom, and Pickering and Gathercole (2004) related individual WM deficits to various categories of special educational needs for students.
Similar to this, individual differences in processing ability have also been used to characterise the efficiency of selective attention (Davies, Jones & Taylor, 1984; Engle, Kane, & Tuholski, 1999; Kane & Engle, 2002), and Eysenck and Eysenck (1979) showed that selective attentional efficiency is affected by the personality dimension of introversion-extraversion. Interestingly, Broadbent, Broadbent and Jones (1986) proposed that correlations between failures of selective attention and the Stroop task (as developed by Erikson and Erikson, 1974) are an indication of individual differences for inhibition.

Elucidating individual processing differences is important for understanding the variations in student learning, because it can guide educators to the most relevant instructional focus. For example, the correlation between active WM capacity and the Scholastic Assessment Test (the SAT; an American college admission and placement instrument that measures general verbal and mathematical reasoning abilities as well as knowledge of particular subject areas) is about .60. However, there is no correlation between SAT scores and tasks that involve only simple, short-term memory capacity (such as repeating words or digits from memory), indicating that active WM is likely to be more important for classroom learning than short-term storage capacity (cf. Ashcraft, 2006). In light of these differences, understanding how to scaffold for WM function becomes a significant factor when it comes to designing student-centred instructional approaches. This sort of knowledge is important to the educational designer precisely because it translates into different learning tasks and different teaching strategies at the individual level of classroom learning.

2.2.2.3 Information processing and IQ

Another, closely related measure of individual differences with respect to learning is the notion of an intelligence quotient (IQ). IQ is generally defined in terms of an individual’s general capacity for mental functioning, including memory, thinking, and learning. IQ tests reveal a wide range of individual differences in ability (Deary, 2001; Vernon et al., 2001); yet correlate well with academic achievement (Brody, 1997; Wechsler, 2003). IQ scores are related to information processing ability across a range of functions, including speed of processing (Schmid, Tirsch, & Scherb, 2002), metacognitive or strategic processing (Miller & Vernon, 1992), and comprehensive WM
function (Thorndike, Hagen, & Sattler, 1986). Indeed, IQ differences appear to correspond to the efficiency of WM function across an array of different academic and learning-related areas (Cariglia-Bull & Pressley, 1990; Di Vesta & Di Cintio, 1997; Jurden, 1995). In this respect it is to be noted that gifted students display both high IQ and distinct domain-specific WM associations (Dark & Benvow, 1991), and that certain disabilities associated with low IQ also tend to exhibit distinct WM deficits (Pickering & Gathercole, 2000).

It seems, therefore, that IQ differences are closely aligned with WM efficiency, and may reflect fundamental variations in the way individuals encode and decode information (Demetriou et al, 2002), in the speed at which information is processed (Grant & Gomez, 2001), and in the ability to respond to novel information (Kail, 2000). In turn, WM tasks correlate highly with academic achievement as well as with intelligence tests (Daneman & Merikle, 1996; Engle, Tuholski, Laughlin, & Conway, 1999), and are also reliable predictors for general learning (Kyllonen & Christal, 1990; Miyake, 2001). Overall, the relationship between information processing and IQ seems to stem from the role of WM in terms of processing speed, processing type, and strategic processing factors.

From an educational perspective the notion of IQ is often described in terms of outcome performance, that is, the effectiveness by which an individual is able to complete a learning task. However, a range of effective outcome performances characterise the average classroom, and a question frequently asked by educators is how to account for this range of individual differences in terms of designing instructional approaches that cater for the various aspects of learning. A core function of instructional design is to encourage and facilitate the use of intelligence in the most effective and efficient manner possible (Block & Pressley, 2002; Byrnes, 2001). Understanding how design factors interact with the principles of effective learning is, therefore, paramount to the consideration of effective teaching (Shulman, 1987; Smith, 2004). One example of this can be seen in the way our understanding of a limited capacity WM has produced instructional design features based on the organisation of information into “chunks” (categories or clusters) of information, in order to decrease the capacity demands made on processing at that level. This is important to the thesis because information processing theory highlights limited capacity and the role of selective attention as crucial elements of
2.2.3 The architecture of information processing

Structurally, information processing theory envisages information as flowing through a series of processing stages, similar to the way a computer processes data (Rose, 1992). These stages are generally conceived as distinct phases relating to processing, which can be distinguished at a functional level. The general distinctions made concerning information processing include sensory input information, active or working memory (WM) information, and long-term or archival information. The crucial role of WM will be elaborated in sections 3.1 and 3.2 of the review. However a brief description of how each of these processing stages is conceptualised will be given here, to provide a coherent overview of information processing theory, and to illustrate the general relevance of this theory to the thesis.

2.2.3.1 Sensory memory: Perceptual encoding and the nature of encapsulation

Initial information processing involves the encoding of sensory stimulus information (visual, auditory, touch, smell, taste, and kinaesthetic). This is similar to the way data is input to a computer through a keyboard (touch), mouse (kinaesthetic), media inputs (hearing and/or visual), or a web cam (visual). The sensory stage of processing is characterised by a large information register yet limited processing duration, with information persisting in the visual register (iconic memory) for just 0.25 seconds, while it exists in the auditory register (echoic memory) for 4 – 5 seconds (Anderson, 2000; Lutz, 2000; Posner, Snyder, & Davidson, 1980). It is generally believed that information at the sensory stage is highly encapsulated (Fodor, 1985; Stanovich, 2000), that is, that each sensory mode is dedicated to processing a specific type of information only. Encapsulation means that the sensory module does not have to make discriminations about the information. In turn, because each sensory mode can process only a single type of information, very fast, automatic processing can occur at the sensory stage of processing. The idea of encapsulation has implications for instructional design, by suggesting that how the teacher encodes information is as important to effective learning as is the content of the information itself. For example, instructional information
concerning spatial relationships is more efficiently encoded using a visual mode of reference, rather than, say, trying to encode the information in an audio-descriptive format. Just as a computer uses dedicated types of software to process different information types (bit-mapped or object-oriented software for visual images, script-driven software for word processing), so the human mind seems to encapsulate information at the sensory stage of processing, in order to facilitate faster, more efficient processing of large amounts of stimulus information from the environment.

Encapsulation may also provide an important principle concerning the ongoing processing of information. Some research (Paas & van Merrienboer, 1993; Schneider & Shiffrin, 1977; Stanovich, 1990; Sweller, van Merrienboer, & Paas, 1998) suggests that a type of encapsulation can also operate at higher levels of processing. Mnemonics are a form of organisational encapsulation that provide for more efficient processing of schematic information and greater recall of information. Thus, as a processing principle, encapsulation may prove important to the efficient processing of information at various levels of processing.

Looking at the proposed nature of sensory information processing, it is apparent that an enormous amount of information is encoded at the sensory stimulus stage, yet this information remains activated for only a brief amount of time. Thus, overall, the nature of the sensory register is such that large amounts of information are processed, yet only briefly, and that little or no manipulation of the information occurs. The principle of encapsulation is important to understanding how sensory processing might affect classroom learning. As suggested in figure 2.1, the disposal of non-relevant information at this early stage of processing involves the filtering of extraneous information, not inhibition in the sense used for the thesis. However, the nature of information processing changes as the information moves into the working memory system, as does the nature of inhibition. A detailed review of working memory function in relation to learning is presented in section 3.2 of the thesis, but a brief overview of working memory will now be undertaken, in order to furnish a coherent mapping of overall information processing, and to convey the general importance of WM to the thesis.

2.2.3.2 Working memory: Adaptive integration within a limited capacity system
From the sensory stage of processing the information is sent to working memory (WM), conceptualised as operating similar to the Random Access Memory (RAM) of a computer (Mayer, 1996; Rose, 1992). WM is considered the forum in which information from the outside world and from permanent memory is integrated (Sweller, 1999). It utilizes data from both sensory memory and long-term memory, and discriminates whether the information is to be processed further (either by encoding it into long-term memory or acting on it immediately), or suppressed from ongoing processing (by allowing the information to decay or by displacing it with different information; c/f Miyake & Shah, 1999; Lutz, 2000; Morra, 2000). A key characteristic of this stage of processing is that the WM system is limited to processing about seven (7) ‘bits’ of information at a time (Baddeley & Hitch, 1974; Daneman & Carpenter, 1980; Miller, 1956). Important to the thesis, WM is proposed as the area of mind where information is manipulated in relation to attentional focus and in relation to the goals or intentions of the individual (Atkinson & Shiffrin, 1968; 1971).

According to Dennett (1991), WM is where consciousness occurs. Indeed, the concept of limited processing capacity is based on the idea that individuals cannot maintain in consciousness an unlimited number of items simultaneously or for an indefinite period of time. Theoretical advances in cognitive and neuropsychology have supported the notion of limited capacity processing, and because of this have placed WM as a central construct in the understanding of overall information processing behaviours (Conway et al, 2005; Miyake & Shah, 1999; Richardson et al, 1996). WM is also viewed as functioning in a domain-general manner (Anderson, 1995; Engle, 1996; Goldman-Radic, 1987), making it central to learning across all curriculum areas.

Neuropsychological research associates several WM functions with discrete brain areas, including the lateral frontal and inferior parietal lobes for short-term verbal memory (D’Esposito, Aguirre, Zarahn, et al., 1998; Markowitsch et al., 1999), the parieto-occipital region and striatófrontal lobe function for visual-spatial memory (Le Bras et al., 1999), and the anterior cingulate cortex and prefrontal cortex for executive control (Cohen, Botvinick, & Carter, 2000; Denckla, 1996; Kane & Engle, 2002; Zanto & Gazzaley, 2009; although other structures may also be involved, cf. Shimamura, 2000; Wang, Ulbert, Schomer, Marinkovich, & Halgren, 2005). The utility of WM as a means of explaining processing ability is well established (Miyake, 2001), and the construct
displays high levels of validity and reliability (Conway et al., 2005). In addition, measures of WM correlate quite well with academic achievement and with intelligence tests, as well as being good predictors of general learning (Engle, Tuholski, Laughlin, & Conway, 1999; Miyake, 2001). An understanding of how the various functions associated with WM interact with classroom learning hence appears relevant and appropriate to the scope of the thesis.

According to Richardson (Richardson, Engle, Hasher et al., 1996) the term “working memory” was first used by Miller, Galanter, and Pribram, in a 1960 publication entitled Plans and the Structure of Behavior. However since that time there has been a diversity of models put forward to describe working memory (WM). In a well edited overview of WM, Miyake and Shah (1999) noted ten distinct models of WM processing, with each representing a different understanding of some theoretical, functional, or neuro-anatomical aspect of processing at the WM level. Although this review is quite theoretical, it notes a number of significant issues relating to WM which are also of concern to the thesis. These include how information is encoded and maintained in WM, how information is controlled and regulated at this stage of processing, what sorts of distinctions occur in the control processes, how WM interacts with language comprehension, and what type of relationship exists between WM and selective attention. Some of these issues are addressed further in section 3.2 of the thesis, yet the basic connections to these concerns can already be seen in the brief overview presented here.

Concerning how information is encoded and maintained in WM, and how it might be regulated, an early, influential model of working memory (WM) has come from Baddeley and Hitch (1974). In their model, WM is viewed as a modular component system, consisting of two “slave” systems and a “central executive”. The slave components include a “phonological loop” (for storing phonological information) and a “visuo-spatial sketchpad” (for storing visual and spatial information). Thus, specific information is encoded into each of these “slave” systems, to provide temporary storage of information as it is being processed in WM. The central executive is seen as an organising component, responsible for the supervision of information integration and for coordinating the slave systems. Baddeley (2001) extended this model by adding a fourth component, the “episodic buffer”, which adaptively integrates phonological, visual, and spatial information with semantic information. Episodic memory is an aspect of long-
term memory, and is discussed in section 2.1.3.3, but Baddeley’s use of this term in relation to his component reminds us that discriminating and regulating information requires some sort of metacognitive processing function, in order to select and suppress various information inputs and associations in a coherent and meaningful manner. The thesis position is that our understanding of the regulatory function of WM has not included sufficient evidence regarding the role of inhibition in relation to classroom learning.

The need to increase our understanding of inhibition in this respect may also be seen in Schneider and Shiffrin’s (1977) concept of executive processing, which they termed controlled processing. This concept represents an interesting approach to how executive function might operate in relation to classroom learning, because it involves processing situations where the information is organised or formatted in an inconsistent manner (a “varied mapping condition”). In such situations, individuals are required to pay very close attention to the congruent, task-relevant aspects of information, as it is embedded within a larger framework of irrelevant, incongruent information. This understanding of a complex or complicated information environment seems remarkably close to what occurs in the average classroom, where factors such as variations in student ability levels, differing paces of learning, unexpected or disruptive events, the need to monitor widely and to give different instructional supports as needed, simultaneous inputs from different conversations occurring, and the multimodal formatting of information, all create a multi-input information situation that can, at times, verge on the chaotic. It is precisely this sort of processing environment that the thesis seeks to support, by accentuating the role of instructional formatting as an aide to the executive inhibitory function.

The formal concept of executive function (EF) is well established in the area of neuroscience (Miller & Cohen, 2001; Stillings, Weisler, Chase et al., 1995), and is generally used to represent how the human information processing system is regulated at the WM level. This concept is used to explain how human processing is able to adapt to novel situations, forward plan activities, set goals, problem solve, and learn intentionally (Müller & Knight, 2006; Shimamura, 2000; Vernon, Wickett, Bazana, & Stelmack, 2001). This aspect of WM is important to the thesis because EF includes selective
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Chapter 2 Review of the Literature (part 1)

attention, inhibition, and multi-tasking (Anderson & Green, 2001). Importantly, recent research suggests that the ability to focus attention on task-relevant information while ignoring distractions is crucial to effective WM function (Aron, 2007; Zanto & Gazzaley, 2009). Thus, if cognitive pedagogies are to carry forward in producing effective instruction, then the relationship between EF and classroom learning will need to delineate the influence of inhibition as an aspect of instructional design, in order to support overall WM function.

Inhibitory influence is detailed in sections 3.4 and 3.5 of the thesis, but for now it is to be noted that this overview of WM has underlined two important concepts for the thesis: limited capacity processing and adaptive executive function. This part of the review suggests that inhibition is connected to the executive functions of WM, and that a better understanding of inhibition will help support limited WM capacity for the learner. This overview thus accentuates the implications of a limited processing capacity for classroom instruction and classroom learning. It makes the point that the processing limitations affiliated with WM relate to specific aspects of selective processing, and involve the need for some sort of adaptive, executive processing control, in order to both selectively attend and selectively inhibit information. A primary goal of selective processing is to meaningfully integrate activated information with the knowledge stored in long-term memory. With that in mind we now pass onto a review of long-term or archival processing. A key question at this point is how the short-term storage information from WM is integrated into long-term memory.

### 2.2.3.3 Long-term memory: Integrated meaning and conceptual understanding

Information passes from the WM stage of processing into more or less permanent storage in long-term memory (LTM). Important aspects of information at this stage of processing are that it is virtuously infinite in capacity (Landauer, 1986), and that it can endure throughout an individual’s entire life (Bahrick, 2000). The contents of LTM are widely categorised into two broad domains: *Explicit memory* (LTM that we are consciously aware of), and *implicit memory* (LTM that we are not consciously aware of, yet are influenced by). Neuropsychological evidence suggests that different neural systems may exist for these explicit and implicit memory distinctions (Ashcraft, 2006).
Within each of these categories of LTM content, further distinctions are also made. The explicit category is seen to contain episodic memory (the ability to recall personal experiences from our past) and semantic memory (facts and generalized information, including verbal information, concepts, rules, principles, and problem-solving skills). The implicit category is viewed as containing conditioned responses (classical conditioning effects, such as emotional reactions), procedural memory (motor skills, habits, etc.), and priming effects (the implicit associations which activate concepts in LTM, cf. Gray, 2002; Medin, Ross, & Markman, 2005). Figure 2.2 provides an overview of these categories and relationships. It is important to note that the various parts of LTM do not operate in isolation from one another. While there is not a full consensus as to precisely how they all work together, it is clear that they are related and overlap, and that the contents of LTM function to archive information for the processing system.

**Figure 2.2 Overview of information organisation for long-term memory.**

Key questions concerning information at this point of processing concern how the information in WM has made its way into LTM, and how it is retrieved from LTM (Anderson, 2005; Baddeley, 1999). The primary strategy for transferring information from WM into LTM is referred to as encoding (or elaboration). This refers to the process of relating new information to other information that is already stored in LTM.

Information that is encoded into LTM becomes archival, stored in the form of schemata and elaborated into propositional networks (Alba & Hasher, 1983; Marshall,
The key determinant of how this occurs seems to be how the information was processed in WM, especially whether the information was rehearsed at a maintenance level or an elaborative level of rehearsal. Each of these rehearsal types seems to influence how well something will be encoded, and later recalled, at the LTM stage of processing. Maintenance rehearsal simply involves rote repetition (repeating the to-be-remembered information over and over again, mentally). Although this rehearsal strategy has been shown to maintain the information in WM for reasonable periods, it does not appear to lead to enhanced recall of information from LTM (Ericsson, Chase, & Faloon, 1980).

Elaborative rehearsal is a more effective strategy (Craik & Lockhart, 1972). This strategy involves actively searching for the meaning of the information, and then relating this to current knowledge. This rehearsal type typically requires greater mental effort than maintenance rehearsal, but the added mental investment seems to pay off in terms of later recall effectiveness. One interesting finding concerning elaborative rehearsal comes from studies of incidental learning (i.e., learning without intent). Some of this research suggests that elaboration effects (i.e., increased recall of information) occur regardless of the intent to learn (Tulving, 1989), and this probably relates to the issue of priming. However, intent to learn still influences the type of memory strategy that individuals choose to employ, with individuals having a strong intention to learn more likely to spontaneously adopt an elaborative rehearsal strategy, as opposed to a maintenance strategy. The point of interest here is that elaborative strategies stress attending to the meaning of information, rather than to other features of the information. Thus, the link between type of memory strategy and effective learning concerns how attentional processing encodes information into LTM in ways that exhibit a meaningful structure. This brings us to the discussion of how information is processed in LTM.

Various theories have been presented concerning how the information in LTM is processed. For example, Semantic Network theory (Fuster, 1997) considers information as stored in conceptual networks, with the relationships between concepts (called ‘nodes’) acting as pair-wise associations. This theory considers concepts as a basic unit of associative meaning. However, it also allows for concepts to associate in larger networks, suggesting that we tend to store information in ‘meaningful’ ways (that is, in ways that are able to relate new information to information already stored in LTM). This theory
suggests that the processing of information in LTM involves the activation of associative conceptual meaning.

On the other hand, Feature Comparison theory (Smith & Medin, 1981; Tentori et al., 2007) views concepts as stored more simply, in terms of universal features and typical features (for example, we might store the concept of “coffee” as occurring within the broader domain of useful plants, yet generally think of the functions of coffee as being a drink that tastes robust, contains caffeine, and interferes with sleep). From this perspective, the information in LTM is processed according to a sort of hierarchical, top-down activation system. In this approach, the more general conceptual domain is activated first, and then the more specific features of the concept relating to context are activated.

Probably the most common understanding of how information is encoded into LTM is that of propositional networks. In this respect Anderson’s ACT-R theory (Anderson, 2005; cf. Driscoll, 2004), has posited knowledge as being stored within large propositional networks that contain a number of information ‘nodes’. Importantly, each ‘node’ within the network represents a logical proposition, including a subject and a predicate. This model of LTM allows the brain to search out information using Boolean logic (an algebraic-based logic system, wherein computations concerning ‘truthful’ conceptual associations are used to activate relevant information), and thus provides the framework for a deeper analogy between computer processing and human cognition. The value of this approach is that it augments the meaningfulness of information. Because concepts are inter-related according to their ‘truth value’, individual propositions can be different, yet still share information. This allows the Boolean activation process to operate similarly to language, providing a basis upon which to structure LTM information in a semantic format.

This also means that the propositional network model can provide a framework for evaluating the linguistic organization of knowledge at a classroom level. In much the same way that computer networks are evaluated by the multiple connections and speed of processing they afford users, the linguistics of instructional information can be evaluated according to its propositional complexity and the level of effort this requires from learners. Propositional complexity may be related to the way language is used in
instruction. Effort can be measured by the amount of cognitive load experienced by the learner in relation to the instructional language. Propositional network theory is thus important to the thesis because it indicates that the linguistic features of classroom instruction may provide organisation to learning-related information, and that this is integral to the ability of students to retrieve knowledge. Often teachers will refer to high-achieving students as being more ‘connected’ to the learning. According to propositional network theory, this occurs because these students are able to activate more links among their knowledge schemata, and thereby retrieve the information more easily. An important hypothesis of the thesis is that information retrieval involves an interaction between the propositional complexity of instructional organisation and the learner’s information processing ability. The discussion of cognitive load theory (section 3.5) will explore this hypothesis in greater detail. For now, however, we continue our exploration of how information is encoded and retrieved from LTM by reviewing schema theory, as this theory provides particular notions and concepts relating to the structure of LTM.

2.3 Schema theory

Schema theory is important because it suggests how information is structured in long-term memory (LTM), and because it offers a rationale as to why attending to the meaning of information improves memory recall. It thus provides a more local and specific rationale for the relationships and assumptions posited by the thesis. The term schema was first used by Piaget (1959; 1977; cf. Svoboda, 1973), to refer to how knowledge is mentally organised, but Anderson (1995; 2000; 2005) has applied schema theory to memory and learning in considerable detail. Piaget postulated that schematic information can be incorporated via two basic processes: by assimilation (where the information is associated to existing knowledge structures) or by accommodation (where new knowledge structures are constructed for novel information). However some theorists have interpreted schematic incorporation in more nuanced terms, using the notions of accretation, tuning, and restructuring (Driscoll, 1994; Rumelhart & Norman, 1978). Accretation relates to assimilation, where the learner incorporates information into their existing schema without having to make changes to the overall schema involved. Restructuring is like accommodation, where the new information is so novel or unfamiliar that an entirely new schema must be created to incorporate the information. Tuning is between these two, and refers to situations where new information can be
incorporated into an existing schema, yet requires the modification of the schema. Tuning can thus be associated with the Vygotskian idea of a zone of proximal development, a hypothetically ideal area of cognitive learning, where learning tasks require the learner to both assimilate and accommodate the information (cf. Woolfolk & Margetts, 2009).

Schematic information is generally viewed as being associated into clusters or ‘networks’ of commonly activated patterns that form categories, concepts, propositions, or scripts representing our knowledge and beliefs about the world (Spicer, 1998). According to Jonassen and Reeves (1996) the basic organisation of this knowledge is derived from the meaningful relationships that exist between the concepts and propositions, indicating that the most salient fact about schemata is that they are semantic constructions. This is important to the thesis because it calls attention to the associative nature of schematic information. This also raises the question of how particular schematic associations become activated.

### 2.3.1 Schematic activation and information priming

Schema activation involves the relationship between new information and prior knowledge. In relation to the propositional network understanding of LTM, the notion of spreading activation is used to explain this relationship. According to Anderson (2000), the ‘nodes’ (concepts) of a propositional network can be either active or inactive at any given time. Anderson suggests that associations between the various network nodes contain different activation ‘thresholds’ (an activation threshold is the level beyond which neural stimulation excites the node to the level of activation, that is, to the level of WM awareness). Spreading activation occurs as the strength of an activation signal exceeds the threshold value of the most relevant nodes within a network, to produce an overall activation pattern that is coherent and accessible to working memory.

Important to the thesis, the principle of spreading activation states that as one schema within a network is activated, associated schemata are also activated, but that this effect weakens as the spread of activation moves further away from the initial activation source (Anderson, 2005; Shastri, 2003). Thus, depending on their position and level of excitement within the activation wave, some schemata may be only partially activated. This pertains to the notion of information priming as envisaged by the thesis, and
provides a rationale for the particular assumption that instructional priming in the classroom can be a factor in the learner’s ability to process instructional information efficiently. *Cued recall* is a positive instance of this priming effect (Sternberg, 2006). In cued recall, schemata that are strongly associated due to frequent activation can become progressively primed in relation to a given stimulus, allowing for progressive learning.

Positive priming effects also underscore the principle of *automaticity*, as envisaged by Cognitive Load Theory (Sweller, 1994; 1999; cf. Stanovich, 1990; Sweller, van Merriënboer, & Paas, 1998). Automaticity refers to the idea that schemata that are accessed often in relation to specific learning tasks or areas of knowledge require progressively less activation for retrieval, becoming thereby more ‘automatic’. Because of this, automatised learning tasks make little or no demands upon the limited capacity of WM, lowering the amount of cognitive load experienced in relation to the task.

### 2.3.2 Errors in schematic activation

The opposite of cued recall would be when schematic information is presented or organised in a manner that relates it widely to other schemata. This sort of priming could result from poor organisation and/or presentation of information, and may form a type of *cue overload* effect (Galotti, 2008). If the instructional cues relating to a learning task naturally cause the activation of many different schematic relationships, this may cause the individual to become aware of too much information they were, in fact, not trying to recall. This represents an opposite to automaticity, and can be expected to make greater demands on WM, increasing the amount of cognitive load experienced in relation to the task.

As well, widely-cued activation would involve both existing knowledge and inferences about how information might ‘fit’ into the spreading activation wave. This means that, in light of the principle of spreading activation, widely-cued schematic processing would be more likely to contribute to errors in memory encoding and memory retrieval. According to Cohen (1993), schematic processing can influence such errors in at least five different ways:

1) By *misguiding attention*, and thus encoding poorly
2) By abstracting the encoded information, causing it to lose much of its specific detail

3) By incorrectly integrating prior knowledge with new perceptions

4) By normalising novel or unexpected information, to fit into existing schemata

5) By providing an incorrect retrieval cue via schemata that prime for outcome expectancy

Effective use of schematic priming is, therefore, an important concern in relation to instructional organisation, and seems to occur inherently when clear activation strategies are put into play, such as the use of analogy, metaphor, comparison, mind mapping, and specific learning prompts (cf. Chi, Glaser, & Rees, 1982; Gick & Holyoak, 1983). Such strategies are effective because they can activate both explicit and implicit memory systems, yet spreading activation seems to occur primarily because of the way implicit memory often manifests as a priming effect. Because of this, the thesis assumes that the way learning-related information is organised is paramount to the type of priming effect that will occur in a classroom. This perspective is also supported by Lutz (2000), who noted that various organisational strategies can be used to encode information into schemata-like relationships, to assist the learner in processing the information.

The overall considerations of schema theory are that teachers need to make clear instructional connections, that prior knowledge plays an important role in learning, that it is often beneficial to organise learning tasks in a way that is meaningful to the learner, and that perceptual and attentional processes need to be considered in the design of instruction. Schema theory thus encourages instructional designers to acknowledge and value the individual knowledge and abilities that students bring to the learning process, stressing the relationship between pedagogy and learning (Kearney & Treagust, 2001).

Importantly, schema theory details how the elements of knowledge are organised to promote efficient information processing, suggesting that schematic processing guides the encoding of information, its organisation in storage, and the decoding cues that provide effective retrieval of information. By delineating the role of specific information processing functions, and how these encapsulate the learning process at a fine-grain level, the thesis seeks to investigate the relationship between learner-centred factors and pedagogical or instructional factors, and how these interact to produce differential
learning experiences and outcomes. At the heart of this relationship sits the WM system, in particular the executive functions relating to selective attentional processing. Review of this system, including how these particular functions relate to the thesis, continues in sections 3.1 – 3.5 of the review.
CHAPTER 3: REVIEW OF THE LITERATURE (cont.)

We believe that research on interference and inhibition should soon address two fundamental issues. The first is the relationship between interference and inhibition...The second issue that research on interference and inhibition will have to address is the core assumption that resistance to interference (or inhibition) is implicated in most aspects of cognition, including comprehension and reasoning. (Dempster & Brainerd, 1995, pp. 404-405).

3.0 Introduction

This chapter continues the literature review, by examining the literature relating to working memory, the executive control processes, inhibition, cognitive priming, and cognitive load theory. This chapter also provides a summary of the overall literature review findings. The areas covered in this part of the review are as follows:

3.1: A review of the working memory (WM) system in relation to attentional processing
3.2: A review of cognitive inhibition in relation to classroom learning and teaching
3.3: A review of cognitive priming relative to the inhibitory function
3.4: A review of cognitive load theory in relation to priming and inhibition
3.5: Executive summary of the overall literature review findings

This part of the review begins by providing an overview of working memory (WM) as the pivotal aspect of information processing relating to the thesis, with the executive control (EC) functions of WM delineated as necessary to understanding how cognitive inhibition can present a specific focus for the thesis. The relationship between inhibition and priming is then examined, as this relationship establishes a connection between inhibition and cognitive load. Overall, this part of the review supports the thesis position that the WM executive function relating to inhibition furnishes the neuropsychological mechanism by which cognitive load is experienced. According to this review, inhibition accords an explanatory rationale for cognitive load theory.

3.1 A review of the working memory (WM) system in relation to attentional processing

A fundamental assumption of the thesis is that the limited processing capacity of WM determines the shape of learning. More than half a century ago, George Miller (1956) conducted a series of studies designed to identify the number of items that could be accurately
remembered, thereby establishing the capacity of recall memory. He used the term *short-term memory* to represent the brief memory component of the information processing system. Miller’s research formalised processing constraint as a principle of cognition by suggesting that the capacity of short-term memory was limited to about five to nine different items of information at one time (Miller noted this as the ‘magical’ number of about 7 [+ or – 2] bits of information). Although later research found that this limitation can be overcome to some degree by using mnemonics (Atkinson et al., 1999; Levin, 1994), Miller’s construct of short-term memory nevertheless established the notion of capacity constraint as a principle of information processing, as well as the need to emphasise active manipulation of information at this stage of processing in order to assist in the recall of task-relevant information.

Miller’s (1956) study laid the foundation for researchers to advance their understanding of information processing and memory. In 1986 Baddeley proposed a more complex, modular model of memory that included three main components: the *phonological loop*, the *visual-spatial sketch pad* (both short-term memory stores), and a limited capacity *executive control system* that governed the information encoded into these stores. Baddeley later (2001) added a fourth component, termed “the episodic buffer”, and suggested that each subsystem possesses limited processing resources, with the executive control system regulating the activities of the two subsystem stores, and the episodic buffer regulating the interface between the working memory system and the information contained in long-term memory. Some research suggests that these types of functions are involved with the prefrontal cortex, an area of brain-based function often associated with WM (Andrade, 2002; Kroger et al., 2002). Research also suggests that this area is involved in the regulation of information relating to sensory input information, information from long-term memory, and the relevant task or goal of the processing (Miller & Cohen, 2001).

In relation to this regulatory role, the term *executive function* (EF) has been used to refer to various complex or higher-order mental processing functions, such as are involved in goal-directed behaviours (Morra, 2000; Pintrich, 2000), planning and organising activities (Antonietti, Ignazi, & Perego, 2000), evaluation and discriminatory functions (Neill, Valdes, & Terry, 1995), task-switching strategies (Mitchell, Johnson, Raye, & Greene, 2004), problem-solving activities (Fincham, Carter, vanVeen, Stenger, & Anderson, 2002), and self-reflective awareness (Zimmerman, 2000). Various measures of executive function provide convergent
evidence (Davies, Jones & Taylor, 1984; Morra, 1994) that the executive processes are important to complex cognitive activities, including not only linguistic and mathematical learning, but also metacognitive ability (Antonietti, Ignazi & Perego, 2000; Karatekin, 2004), complex problem solving (Engle, Kane & Tuholski, 1999), and even occupational success (Kyllonen & Christal, 1990). Measures of executive function also display high correlations to both IQ and fluid intelligence tests (Conway, Kane, Bunting et al., 2005; Fry & Hale, 1996; Gathercole & Pickering, 2000; Miyake, 2001), suggesting that research into the relationship between executive function and classroom learning will provide a fruitful area for applied understanding.

Importantly, inhibition is seen to develop differently to other aspects of executive function, with task switching ability (which requires significant inhibitory control) developing more slowly than other aspects of executive function (Davidson, Amso, Anderson & Diamond, 2006; Diamond, 2002). In particular, task switching activities seem to make simultaneous demands on both the memory components of EF (involving representational holding) and inhibition (involving top-down executive control over the processing), and this may be precisely the sort of processing demands that commonly occur in classroom learning situations.

Executive function (EF) is associated with the prefrontal cortex (Denckla, 1996), and damage to this region seems to result in a disruption to EF behaviours (Pritchard & Alloway, 1999). Of import, Shimamura (2000) has suggested that the prefrontal cortex acts to filter attentional salience, and Knight and Grabowecky (1995) have shown that individuals with damage to the prefrontal cortex exhibit significant impairment in their ability to inhibit irrelevant (non-salient) information. This supports the thesis position that a key role of EF is the inhibition of irrelevant information in relation to selective attentional processing.

3.1.1 Limited capacity and selective attention

According to standard dictionaries of psychology (Colman, 2001; Reber, 1995), selective attention refers to the ability to focus on certain stimuli or tasks while simultaneously ignoring others. Selective attention models tend to reflect the theories of attention, and generally differ one from another in terms of whether task-relevant attentional focus occurs primarily pre or post-selection of the attentional information (Broadbent, 1970; Chun & Wolfe, 2001;
MacKay, 1973; Treisman & Gelade, 1980; Wood & Cowan, 1995). Our understanding of selective attention comes largely from research investigating the effects of visual distractions upon complex WM function (de Fockert et al., 2001), spatial and non-spatial modality differences for WM processing in relation to selective attention (Crottaz-Herbette, Anagnoson, & Menon, 2004), the neuro-anatomy of attention (Müller & Knight, 2006), and attentional dysfunctions (Ghajar & Ivry, 2009). The findings of such research tend to confirm a major role for WM in the control of selective attention, and suggest that selective attention is a multi-dimensional construct, which coordinates distinct neurological processes and components in modality-specific ways (Rämä & Courtney, 2005), in order to allow selectively focussed mental operations over a sustained period of time (Yoon, Curtis, & D'Esposito, 2006).

Selective attention has been theoretically conceived in a number of different ways. Filter theory (Broadbent, 1970) is concerned with the limited cognitive resources available for processing the features of attentional input information. This theory proposes that we are able to attend to some sensory inputs, while ignoring others, because attentional filters block sensory inputs that do not contain relevant feature information whenever the number of attentional inputs exceeds our processing capacity. Of course, this suggests that attentional selection is driven by the feature level characteristics of attentional information, and thus filter theory fails to adequately address the influence that contextual meaning has upon the selection process. This problem is acutely highlighted by what is known as the “cocktail party” effect (Moray, 1959), which shows that even when information overload is quite high; the salience of information can override attentional filtering.

Attenuation theory partly addresses this problem, by proposing that attentional processing is directed by the meaning of the input information, instead of its features (Treisman, 1960; Treisman & Gelade, 1980). Treisman (1960) illustrated this by having people “shadow” (repeat) only one of two messages presented simultaneously in each ear (a dichotic listening task), with the shadowed message being switched to the opposite ear halfway through the task. Most of her study participants were able to continue shadowing the relevant message, without even being aware that it had changed to the other ear. Treisman interpreted this to signify that attentional processing had been maintained on the basis of a top-down, contextual process, based on the meaning of the information. Of interest, Conway, Cowan, and Bunting (2001) have shown that the shadowing effect corresponds to individual differences in working memory. This
connects attentional processing to WM, and further suggests that attentional regulation involves individual differences in processing capacity.

Whereas Treisman’s attenuation approach allows for some meaningful processing to occur during the early processing of information, late-selection theory (Deutsch & Deutsch, 1963) postulates that all sensory input information, even when unattended, is processed in relation to meaning. Deutsch and Deutsch proposed that sensory information gets processed non-selectively across all attentional channels, until such time as it reaches a short-term memory store. This approach to attentional processing combined the simple “gating” view of filter theory (that attentional processing inhibits non-salient information on the basis of the features of the information only), with Treisman’s idea (that non-salient information is simply attenuated, and thus available to some higher or more meaningful processing), to arrive at the position that attentional gating occurs at the short-term memory stage of processing. At this point in attentional modelling, the notion that selective attentional processing is the product of WM limitations becomes an explicit assumption.

In this respect, a number of attentional-resource theories of selective attention have continued to develop (e.g., Kahneman, 1973; Navon, 1984), based on the link between selective attentional processing and WM capacity. Generally speaking, attentional resource theories understand the phenomenon of selective attention in terms of the interaction between task requirements and available processing resources, as controlled by a limited capacity WM system. Capacity theories appear to mirror developments in cognitive and neuropsychology. As Baddeley’s model of WM became better known, and the ability of cognitive neuroscience to identify and map neuropsychological processes improved, the partnership between attentional regulation and limited resource availability became more prominent.

A model of attentional regulation important to the thesis is the attentional networks system of Posner and others (Fan, Fossella, Sommer, Yanghong, & Posner, 2003; Fan, McCandliss, Sommer, Raz, & Posner, 2002; Fossella, Posner, Fan, Swanson, & Pfaff, 2002; Posner & Fan, 2005; Posner, Peterson, Fox, & Raichle, 1988; Posner & Raichle, 1994; cf. Fuster, 1997). Posner and his colleagues have provided neuroscientific evidence indicating that the various processes involved in attention are controlled by distinct areas of the brain. They nominate three different neurological networks as being responsible for this control: an alerting

The underlying premise of this model is supported by other theorists who have developed similar ideas about the structural basis of human memory systems. For example, Smith and DeCoster (2000) postulated a dual-process model of attentional processing, based on the notion that the human memory system is structurally composed of two distinct systems, with one system performing associative retrieval and pattern completion at a more or less automatic level of processing, while the second system forms representations of unique or novel events as the result of more intentional processing strategies. Thus, the idea that attentional processing derives from distinct underlying neuro-cognitive systems, and that these systems account for different types or modes of processing, seems well placed as a conceptual framework for discussing the unique contribution of inhibition as an attentional or executive function.

This particular view of attentional processing is important to the thesis because (as detailed in chapter four), Posner’s Attentional Networks Test (the ANT) has been used in relation to the thesis, to test for individual differences in attentional inhibition. According to Jin Fan (personal communication, April, 2005), the ANT provides a valid measure of “executive attention”, the executive control mechanism responsible for resolving attentional conflict. It is this particular system which corresponds to the thesis focus on inhibition, and allows the thesis to highlight the impact of limited capacity processing on the executive functions. Importantly, the anterior cingulate has been assigned a major role in relation to inhibition as an EF, and may operate as the primary processing control for both selective attention and divided attention (Aron, 2007; Assiter, 2008; Cohen, Botvinick, & Carter, 2000).

Also of importance to the thesis is that attentional processing appears to be affected by cognitive load (Lavie, 1995; Green & Bavelier, 2003). Lavie noted that a direct relationship exists between selective attention and cognitive load, wherein higher cognitive demands made
by a processing task require a narrower focus of attention, and *vice versa*. According to Lavie (1995), when high-load processing conditions apply, all attentional resources are required to maintain selective attention onto task-relevant information. In contrast to this, when the processing demand is low, attentional resources are able to additionally process non-relevant information. This reminds us that effective classroom learning will require careful consideration of the limited capacity resourcing available to the selective attentional functions of WM. This knowledge is important to the thesis because it emphasises connections between attentional processing and brain-based learning, and because it suggests a link between attentional processing and cognitive load.

An attentional resource model of WM that seems to support the relationship between selective attention and cognitive load is the *time-based resource sharing model* (Barrouillet, Bernardin, & Camos, 2004). This theory explains the interaction of maintenance and processing in working memory by assuming that memory trace representations decay unless they are refreshed. Refreshing them requires an attentional mechanism that is also needed for any concurrent processing task. When there are small time intervals in which the processing task does not require attention, this time can be used to refresh memory traces. Importantly, this model predicts that the amount of forgetting depends on the temporal density of attentional demands, viewed in terms of "cognitive load". In turn, cognitive load depends on two variables: the rate at which the processing task requires individual steps to be carried out, and the duration of each step. For example, if the processing task consists of adding digits, then having to add another digit every half second places a higher cognitive load on the system than having to add another digit every two seconds. Adding larger digits takes more time than adding smaller digits, and therefore cognitive load is also higher when larger digits must be added. In a series of experiments, Barrouillet and colleagues have shown that memory for lists of letters depends on cognitive load, but not on the number of processing steps (a finding that is difficult to explain by an interference hypothesis) and also not on the total time of processing (a finding difficult to explain by a simple decay hypothesis). One difficulty that does seem to exist for the time-based resource-sharing model, is that similarity features between memory materials also seems to affect memory accuracy. This suggests that some sort of priming effect may additionally be involved in the amount of cognitive load experienced in relation to attentional processing. Information relevant to this issue is discussed in section 3.4 of the thesis.
3.1.2 Limited processing capacity and divided attention

*Divided attention* refers to the ability to successfully attend to two or more tasks simultaneously, and is also referred to as controlled-attention (Engle, 2002; Schneider & Shiffrin, 1977). Both research and common experience suggest that certain types of tasks are reasonably easy to do together (e.g., walking and talking, singing while playing an instrument, drawing or painting while having a conversation), while others are more difficult (say, reading while speaking, performing math calculations while counting). This is different to selective attention, with the main issue here concerning how limited capacity is allocated to different tasks, and with task-specific allocation and task-general allocation marking the primary distinctions. Evidence for task-specific allocation is provided by studies which show it is easier to perform dissimilar tasks together than similar tasks (Rämä & Courtney, 2005). This assumes that task-specific resources are non-divisible, and that similar cognitive tasks call upon the same mental resources, making it generally easier to perform dissimilar tasks (which call upon different mental resources, although information salience may mitigate this influence, cf. Schmidt, 1995). In support of the limited capacity WM construct, it seems that individuals with greater overall WM capacity are better at controlled attention tasks (Gregory, & Conway, 2007).

On the other hand, much of the evidence for task-general resources comes from studies showing that even highly dissimilar tasks often interfere with one another (Assiter, 2008), and that attention-related WM functions are both inter-related and dissociable (Asloun, Soury, Couillet, et al., 2008). Thus, task-general allocation may represent a different way of interpreting attentional resourcing, rather than representing a distinct segregation of the attentional resources per sé.

Divided attention is important because it allows us to conceptualise the resources available to attentional processing holistically. If we view the resourcing for attentional processing as comprised of a limited set of overall mental ‘tools’ (say, a planning tool, a response tool, an initiation tool, etc., cf. Stillings et al., 1995), then the concept of divided attention tells us that each of these ‘tools’ serves a general function relevant to many different types of processing demands. Similar to sensory processing, these tools could be more or less encapsulated, with each tool available to only a single task of its particular nature at any given time. Thus if two tasks, even dissimilar tasks, require the same attentional tool, the tasks could not be performed simultaneously. This understanding is significant because instead of carving
up attentional processing into dissimilar activities, it simply prioritises the role of inhibition in relation to task suppression (selective attention) and task switching (divided attention), thus marking inhibition as a significant part of the attentional hierarchy. On this basis we would expect to find clear descriptions of how inhibition affects classroom learning in the literature. However a problem exists in this respect, wherein research explicitly examining classroom learning in relation to inhibition appears quite limited.

### 3.1.3 Research examining classroom learning in relation to inhibition

Cognitive research on classroom learning has tended to examine specific learning effects as connected to numeracy and literacy, and in both cases there seems to be limited amount of information relating to inhibition. With respect to numeracy, the current author was able to locate just three studies investigating inhibition as a particular element of the learning process: Swanson, Cooney, and Brock (1993), who looked at the role of individual differences for cognitive suppression in relation to mathematical word problems; Barrouillet, Fayol, and Lathuliere (1997), who studied adolescent learning disability in relation to table-related multiplication distracters; and Passolunghi, Cornoldi, and de Liberto (1999), who investigated inhibition as connected to WM capacity by comparing memory performance between poor problem-solvers versus good problem-solvers. It is to be noted that only this last study included a measure of memory for irrelevant information as part of the research operandi, and none of these studies attempted to define the notion of inhibition as a specific EF operation.

Turning to literacy, Morris (1996) has hypothesised that EF interrelations make it difficult to examine the unique contribution each function might make to written expression. Yet research does suggest that students experiencing writing difficulties may do so because they possess less efficiency in specific executive functions (Berninger, Cartwright, Yates, Swanson, & Abbott, 1994; Berninger Whiteaker, Feng, Swanson, & Abbott, 1996), and Denckla (1996) has proposed a model of EF in which four distinct functions (initiation, sustaining, inhibition of behaviours, and set shifting) are posited as contributing individually to the writing process. In addition, research by Berninger (1999) indicates that the ability to coordinate sustaining and inhibiting behaviours is necessary to effective text composition. Yet none of these studies has delineated the specific contribution of inhibition to the writing process in operational terms, and no rationale has been put forward concerning the particular role inhibition might play in general.
classroom learning. A closer look at inhibition does, therefore, seem in order, to extend our understanding of inhibition as a limited resource function, and to connect it to classroom learning from this express point of view. To this end the review will now examine research suggesting how inhibition might affect learning-related processing. We begin this part of the review by defining inhibition for the thesis.

3.2 Cognitive inhibition in relation to classroom learning and teaching

Cognitive inhibition is a term widely used by cognitive psychologists and neuropsychologists to refer to the suppression of distracting or non-relevant information during on-task cognitive engagement (Barkley, 1997; Harnishfeger & Bjorklund, 1994; Karatekin, 2004; Neill, Valdes, & Terry, 1995; Zanto & Gazzaley, 2009). The thesis acknowledges, however, that distinctions are made in the professional literature concerning the respective roles of inhibition (Dempster, 1991; 1992) and interference (D’Esposito et al., 1999; Mecklinger et al, 2003), and that not everyone agrees that inhibition is a discrete processing function (Davey & Adams, 2004; McClelland, 2000; Rumelhart, 1989; Smolensky, 1988). In light of this, the thesis defines inhibition as referring to the inhibitory function generally associated with WM, and conceptualises this as a functional connection between items of information where, when two or more items are competing for attentional focus, one of the items needs to be suppressed (cf. Dempster, 1992). It is to be noted that the primary goal of the thesis is not to establish that inhibition is a structurally distinct component of WM, but rather to determine whether or not the inhibitory function exerts a distinguishable influence on classroom related processing, especially in relation to the amount of mental effort students experience during classroom learning.

In this respect, it is acknowledged that a sort of inhibitory pathology has been implicated in ADHD (Barclay, 1997; Loo & Barclay, 2005; Wodka, Mahone, Blankner, et al., 2007), with the construct of “response inhibition” being used to provide a reason for the impulsive aspects of this disorder. Yet this construct remains highly contested (Alderson, Rapport, Sarver, & Kofler, 2008), with complex and at times convoluted arguments being put forward both for and against it. As well, the notion of response inhibition in conjunction with ADHD is associated specifically with the area of special needs education, as opposed to the focus on normal performing learners for the current study. As a consequence of this, the current review will not
review the rather extensive literature on inhibition as it is distinctly conceptualised in relation to ADHD.

In terms of the relationship between inhibition and learning, research on mathematics learning has shown that word problems (mathematical problems understood to represent authentic, “real world” mathematical situations) are more difficult to solve than mathematically equivalent problems posed numerically, and that this difference is exacerbated when the word problem contains irrelevant or distracting information (Mayer, 1989). However, the utility of word problems lies in the fact that they provide practice in applying mathematical problem solving skills within a more complex, real-world setting, which generally includes information that is not relevant and often contradictory (Lewis, 1989). This is supported by research showing that the difficulty of word-problem solving stems from initial comprehension of the information (which, if poor, can lead to a less accurate representation of the problem), and that such inaccurate representations occur primarily because individuals are less able to suppress inconsistencies in the way the problem is presented (Hegarty, Mayer, & Green, 1992). Taken together, this indicates that the ability to discriminate relevant information, and suppress irrelevant information, is fundamental to effective word-problem solving (cf. Kouba, Brown, Carpenter, et al., 1988). It also suggests that inhibitory efficiency may be an important factor for individual differences in the ability to solve problems generally.

For example, problem-solving across an achievement task requires efficient information encoding, because the strategic searching for correct, task-relevant information, while simultaneously testing problem-solving strategies by which the relevant information may be applied, will require the inhibition of both low dominance (task-irrelevant) information and more familiar (more automated) problem-solving strategies. Differences in susceptibility to interference may therefore be a key factor in explaining differences in problem-solving ability, and may well require the implementation of teaching strategies that specifically recognise and make some account of inhibition in the overall problem-solving process. From this position, the examination of inhibition in relation to interference appears justified, in order to increase our understanding of how to scaffold for selective attention in relation to classroom learning.

This position is also based on the fact that highly significant correlations have been found between populations exhibiting high susceptibility to interference on the one hand, and
populations showing low inhibitory efficiency on the other. This has lead some researchers (Tipper & Baylis, 1987; Neumann & Deschepper, 1992) to question the categorical distinctions often made between inhibitory constructs. The thesis characterises inhibition as the ability to resolve cognitive interference that results from task-irrelevant information competing with the processing of task-relevant information, and from incongruent information that conflicts with the processing of task-relevant information. This definition accords with the neuropsychological notion that the prefrontal cortex acts as a dynamic filter, and suggests that inhibition can aid selective attention by excluding task-irrelevant information during on-task learning. When attention is captured by multiple information inputs, the ability to inhibit distracting information is crucial to the selection process. A logical proposition to be extended from this is that many difficulties experienced by students with respect to their classroom learning may be explained in terms of poor inhibitory function in relation to environmental interference.

3.2.1 Inhibition and interference

Interference can occur in a proactive manner, where the effects of prior learning act to impede further learning, or in a retroactive manner, where distracting information that occurs after something is learned but before the learning is recalled interferes with the ability to utilise the learning (Keppel & Underwood, 1962). In either case, however, it seems that interference, rather than information decay, is the main cause of forgetting during a learning task. A study of forgetting by Waugh and Norman (1965) used the probe digit task to test whether decay or interference was the main cause of memory failure. Their study used cued digit recall in relation to encoding pace and cue position, to determine whether decay or interference lowered recall the most. Interestingly, the study predicted that the cued recall of digits at a slower pace would produce the lowest memory recall, because the longer time intervals between cues were expected to produce more decay of the information. Yet the actual outcomes of the study contradicted this hypothesis, showing instead that recall was influenced by the placement of the cue digit during the task. This peculiar outcome indicated that interference occurred as a function of the number of interfering digits between the cue and the recall digit (cue position). This finding is important to the thesis because it implies that the number of distractors affect selective attention much more than does the pace of the information, signifying the need to understand inhibition in relation to the principle of spreading activation (as discussed in section 2.2 of the thesis) more thoroughly. As the activation wave for relevant schematic information
spreads across the processing system, multiple attentional sources, or perhaps poorly organised attentional information, can be expected to activate non-relevant and partially-relevant information to a greater degree. In turn, this requires more suppressive inhibition - a limited EF resource - to control attentional focus.

3.2.2 Inhibition and processing bias

An important feature of less coherent activation is that information that is unexpected or contradictory may tend to bias processing in relation to learning tasks. Several studies relating deficits in learning to processing bias seem to reflect this. Looking at self-perception in relation to attentional focus, Bodner and Milculincer (1998) found that perceptions concerning a lack of controllability created an information processing bias in Israeli high school students, wherein students who perceived themselves as unable to exert control over the learning situation displayed a depressive effect (flattened affect and negative motivation) with respect to their educational tasks. Bodner and Milculincer suggest this effect occurs at the cognitive level, due to the way self-evaluative perceptions distort attentional focus.

Martinez (1994) found that manipulating task-relevant feedback in American university students also moderated learning task outcomes. He used intermittent false feedback concerning answers on a quiz to influence students' perceptions of how they were performing, and found that positive versus negative task-relevant feedback exert differential biases on the task-relevant judgements made by students. Task-relevant judgements form an important aspect of processing during the learning process, because they simultaneously involve attention to task-relevant information and the inhibition of task-irrelevant information. The interesting aspect of the Martinez study is that all participants were taken through both negative and positive phases of false feedback successively, and all exhibited similar differences in their processing biases. Thus the research methodology strengthened the interpretation that it was the effects of the instructional feedback that were responsible for the biases that emerged, rather than factors inherent to individual processing style.

3.2.3 Processing bias and mental effort
Martinez’s (1994) findings also indicated that positive task-related feedback tends to increase decisiveness and correct memory recall, and that negative task-related feedback tends to increase effort yet decrease correct memory recall. Although it may seem intuitively logical that negative feedback will lower recall accuracy, the fact that this is combined with increased effort is important for understanding the role of inhibition in this process. Because increased effort is relational to lowered recall, the likelihood exists that the increased effort is somehow responsible for the lowered accuracy. That is, it appears that something about the increased effort either decreases the ability to maintain controlled attention on task-relevant information, or decreases the ability to inhibit task-irrelevant information, or perhaps both. This is an important finding for the thesis, because it emphasises the effects of inhibition in relation to cognitive load.

An earlier study by Webb, Worchel and Brown (1986) may shed further light on this relationship. This study suggested that increased cognitive effort can also be associated with anxiety, but the mechanism for this seems quite similar to the Martinez (1994) study. The participants in this study were again college students, who were given a learning task to complete in which they received randomised false feedback concerning the results of their efforts. False feedback was thus the independent variable of interest in this study, with the amount of anxiety reported by the participants (in relation to how well they were able to predict their own learning outcome) being the dependent variable. Similar to Martinez, these students reported lowest anxiety arousal when perceptions of high-control over the learning situation dominated, and highest levels of anxiety when perceptions of low-control dominated. Of interest however, is that this study found that while low-control perceptions generated greater cognitive effort on the part of participants, they also generated a lowered task-relevant attentional focus, as well as a greater susceptibility to cognitive distraction. This study thus connects outcome expectation and instructional feedback to both attentional bias and mental effort.

These studies are important to the current thesis because research has also shown that bias in the way information is processed can directly affect the inhibitory function in relation to classroom learning. In this respect Lipson (1983) administered reading recall tasks to year 4, 5, and 6 students, involving culturally neutral, culturally relevant, and culturally incongruent information. The culturally relevant task evoked significantly
greater accuracy in the students’ recall of information than either the neutral or incongruent tasks, as expected. More importantly, the culturally incongruent task returned significantly greater recall distortion than the other tasks, and the distortions were biased in the way students elaborated the recall information in line with their existing knowledge and beliefs. What seemed to be happening was that the students inhibited the incongruent information and replaced it with more culturally congruent information, which had not appeared in the actual recall passage. Wood, Groves, Bruce, Willoughby, and Desmarais (2003) explain this type of processing bias by saying that instructional content which conflicts with the learner’s prior knowledge (e.g., prior knowledge and/or expectations) will promote inhibition in connection to the instructional content, in effect suppressing the activation of relevant schemata. As a means of decreasing this type of suppression, Chinn and Maholtra (2002) have suggested that students should be taught scientific observational skills, in order to assist them to better evaluate and accept valid empirical data. Thus one of the more crucial aspects of processing bias involves the way in which new information is connected to existing knowledge, in a way that involves appropriate inhibitory function.

To relate these studies more clearly to the thesis, it seems that both number and type of distractor are important to inhibition as an executive function, and that both kinds of distractor can affect task-relevant attentional processing - thereby increasing the amount of mental effort experienced in relation to the processing - by distorting the processing and incorrectly matching prior knowledge to the task. Importantly, the basis for these effects seems to stem from the relationship between instructional inputs and the principle of spreading activation. When the number of instructional cues is increased, or when instructional feedback does not match with the learner’s expectations, the inhibitory function appears to lessen the coherence of spreading activation. Important to the thesis, it seems that the common denominator in both cases is that a priming effect appears to be involved. For this reason the review will now discuss cognitive priming as the nexus between cognitive inhibition and cognitive effort.

### 3.3 A review of priming in relation to inhibition
WM research indicates that the way in which information is organised has a significant effect on how individuals are “primed” for processing it (Brown, 1979; Roediger, Neely, & Blaxton, 1983). In this respect, the term priming refers to the way information is cognitively activated for ongoing processing, with a bias for positive priming (increased efficiency in the way the information is accessed), or for negative priming (decreased efficiency in the way the information is accessed), occurring due to the way antecedent information is used to organise for on-task processing. An important consideration for learning is, therefore, how the teacher organises instructional information to prime for efficient activation of the information to be learned.

There are two basic types of priming identified in the literature, semantic priming and repetition priming (Posner, Petersen, Fox, & Raichle, 1988). Semantic priming involves the use of semantically associated information to increase the activation of relevant information. Repetition priming involves the use of multiple exposures to the same information, sometimes using variants, to increase the recall of the information. Both types of priming can be understood in relation to attentional theories which allow for the semantic processing of information, and to the notion of spreading activation, which suggests that the amount of activation a prime delivers to information is a function of the associational strength of the prime and the distance of the prime from the information of interest. For example, in relation to attenuation theory, MacKay (1973) showed that the context of linguistic information affects the activation threshold of the information, and that semantic priming can be used to “disambiguate” task-relevant terms. This type of priming has a positive effect, in that MacKay’s work showed disambiguation lowers the activation threshold for task-relevant processing.

Repetition priming represents another instance of positive priming. Repetition priming refers to the facilitation of processing via prior exposure to the relevant information. Schacter (1987) used a word-stem completion task to suggest that this type of priming is connected to implicit memory, and showed that it works best when the priming creates meaningful associations for the information. This indicates that repetition priming represents another aspect of semantic priming. A classroom example of this might be when a student has to make lexical decisions about the meaning of instructions being given (in either an oral or written format), in terms of identifying the meaning of the instruction in relation to prior learning or in relation to a set learning task. When the teacher has clarified key terms and core concepts, organised the
instructional narrative well, and linked the new information carefully to existing knowledge, then a positive priming effect can occur for this type of processing. When this takes place repetition priming can produce a type of practice effect, whereby the learner becomes more practiced in perceiving certain types of instructional information, and then processes this information more efficiently. This would represent one type of organisational encapsulation, scaffolding for efficient processing of the task-specific information.

Repetition priming aligns well with cognitive learning approaches such as Ausubel’s use of advance organisers, and Presseisen’s model of essential thinking skills, because it allows the provision of meaningfully related information in a distributed manner. As an example of this, McKoon and Ratcliff (1980) presented information contained in two short stories to individuals prior to testing them on story content. They found that when test questions were primed using words from the same story as the target information, recall was positively facilitated by greater accuracy and faster reactions times. Yet when the target information was primed using words from the opposite story, even though the study participants had also been exposed to these words, recall was characterised by lowered accuracy and increased reaction times. Thus the associational relevance of the information, rather than mere exposure itself, seemed to prime the activation levels of recall information to a significant degree.

In addition to implicit priming effects, there are more explicit types of priming that can occur due to expectations suggested by the way information is organised. Expectancy-induced priming can occur when large numbers of related words are included in initial information, forming an expectancy set for the meaning of the information. This can represent a negative priming effect, as often shown by the use of lexical decision tasks, where letter strings are presented and individuals have to state whether the string is a word (e.g., doctor) or a non-word (e.g., dotor, cf. Tulving, 1991; Tulving & Schacter, 1990). The important thing about expectancy-induced priming is that it involves making inferences about the meaning of the information. In terms of spreading activation, this means that poor or ambiguous information formatting may be able to induce a type of retroactive interference in classroom situations. For example, if the organisation of information includes implicit retrieval cues that can be associated too broadly to a number of different meanings, or cues that conflict with one another, then processing competition is set up. This could produce a type of fan effect (Anderson, 2000);
wherein the wider the scope of associations relating to a cue, the more diverse the activation path needs to be in relation to processing the information.

Expectancy-induced priming can also involve conceptual processing (Wolfe, Alvarez, & Horowitz, 2000), and may occur when we expect to perceive information in a certain way or in a certain location. Classroom examples of concept-driven priming would include when a student expects to be taking part in an oral discussion of a prior lesson and then is suddenly given a written test, or perhaps when the student is used to the teacher presenting ideas in a visual format and then a casual teacher simply reads information about the ideas. In both cases the student’s expectancies are left unmet, leaving the student to reorganise their attentional focus to the new situation. In such cases a negative priming effect could occur, resulting in decreased efficiency and accuracy for the task-specific processing. In addition, this type of priming effect would not be automatic. It would require greater mental effort and involve more executive inhibition to control for the interference effects of the mismatched processing expectancies.

Priming is important to the thesis because it reminds us that information can have various levels of attentional activation, depending on diverse factors relating to the person, their environment, and the information itself. Priming thus relates directly to attentional activation, and provides a general principle by which inhibition can be linked to cognitive effort. The notion of semantic priming, especially, seems to represent a type of implicit memory effect. It involves the influence of prior knowledge, yet not necessarily with intentional awareness. For this reason, the influence of semantic associations in relation to classroom learning and teaching - how the teacher instructs and organises information, and how the learner creates expectations from this - assumes an important role in understanding how inhibition may influence classroom learning. To better understand this influence, we need to examine the theoretical underpinnings of priming in more detail.

3.3.1 Models of priming

The close relationship between priming and inhibition can be seen in that theoretical information about priming comes mainly from cognitive and neuropsychological studies concerning the accuracy and reaction time (RT) for processing under various inhibitory
conditions. In this respect, cognitive models of how the suppression of distracting or irrelevant information occurs tend to suggest that inhibition takes place due to either the intrinsic nature of the information being processed (the *activation-suppression* model of inhibition), or due to the integrative nature of the attentional systems that are processing the information (the *temporal discrimination* model of inhibition).

The *activation-suppression* model of inhibition (May, Kane, & Hasher, 1995; Stadler & Hogan, 1996; Neumann & DeScheper, 1991; Tipper, 1985; Tipper & Baylis, 1987) postulates that delays in reaction time, between conditions in which a stimulus is repeated and a condition in which no stimuli are repeated, occur because selective attention involves both the activation and inhibition of information (a sort of cognitive balancing act). Here, changes in reaction time occur because the activation or inhibition that occurs for information in one condition carries over to subsequent conditions, affecting reaction time in one of two ways: an increase in RT (negative priming effect), or a decrease in RT (positive priming effect).

In the negative priming effect, information that is to be ignored in an initial learning condition becomes targeted as information to be attended to in a subsequent condition. This is known as an I/A (Ignore/Attend) situation, and results in increased reaction time for the processing, before attentional salience switches from inhibiting the information to attending to it, and an increase in cognitive load, as the need to utilise executive inhibition is increased.

Positive priming occurs within the *activation-suppression* model primarily for *attentional selection*, when the attended information is presented initially (this can take various forms), and then presented again in subsequent conditions that also require attending to the same information (a type of repetition priming). This would be an AA (Attend/Attend) priming situation, and results in shorter RT’s in the subsequent presentation situation.

It is to be noted that positive priming can also take place for inhibition. For example, when to-be-ignored information is presented initially (this can also take various forms), and then presented again in subsequent conditions that also require the information to be ignored. This represents an II (Ignore/Ignore) priming situation, and also results in shorter reaction times in the subsequent situation. Important to the thesis, this suggests that positive priming can be
used to provide more efficient processing in terms of both attention to task-relevant information and the inhibition of task-irrelevant information.

From a different perspective, the temporal discrimination model (Milliken, Joordens, Merkle, & Seiffert, 1998) views priming as the result of competition between different attentional processing systems, the automatic retrieval processing system and the orienting system. In this model, selective attentional systems themselves form the basis for priming effects, by determining how the information is to be encoded.

According to the temporal discrimination model, information is selectively categorised by the attentional system as either familiar (“old”), or as unknown (“new”) information. Information categorised as familiar is processed by the automatic retrieval processing system, which detects similarities between current and prior information for the purpose of integrating the two. This type of information is matched automatically against information already stored in memory, and a positive priming effect takes place. Because this type of priming process is automatic, it results in priming effects that are characterised by shorter response times and greater matching accuracy, with less overall demands being made on the limited processing capacity of the WM system. Automatic processing thus takes less time and requires less processing resources.

An interesting feature of the temporal discrimination model is that new or unknown information must be perceptually analysed, requiring a more complicated, algorithmic process. This approach accords with the conceptualisation of an attentional networks system, in that information identified in this mode is processed by the orienting system, a system that differentiates information on the basis of detecting differences between current and prior knowledge. It is noted that this type of attentional processing does not result in a clear priming effect, as the information is viewed as novel and therefore possesses no prior link to other information. Yet negative priming effects do occur in this model when information is presented in an ambiguous manner. When this takes place an executive selection process is required to make complex, executive discriminations about the information. This process is required whenever familiar information is presented as if it were unknown, a negative priming condition that creates conflict between the automatic and orienting processing systems. In this condition the familiarity of the information triggers the automatic retrieval processing system, while at the
same time ambiguous contextual demands (e.g., poorly formatted instructional directions) also set the orienting system to process the information as if it were “new”. The result is that processing ambiguity, a type of processing conflict, takes place, making it difficult to process the information in its correct temporal order. Under these conditions, conflict between the orienting system (which is responsible for temporal differentiation) and the automatic retrieval system (which is responsible for temporal integration) result in a lowered ability to integrate the information. The notion of processing ambiguity is important to the thesis, because it provides a nexus between attentional inhibition and instructional encoding.

Table 3.1 provides an overview of the various priming effects as they accord to different priming conditions. It is important to note that the results from both priming models are similar in that negative priming is viewed as making significantly greater demands on the executive selection processes, and characterised by longer response times and decreased matching accuracy.

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<tr>
<th>Priming Condition</th>
<th>RT Effect</th>
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<td>Negative Priming</td>
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<td>IA/AI</td>
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<td>Positive Priming</td>
<td>AA</td>
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(Key: I = Ignore condition; A = Attend condition)

Overall, the various, differential relationships that occur between priming condition and reaction time suggest that consistency in the way information is encoded is essential to effective information processing. The activation-suppression model of inhibition suggests that selective attention relies on a combination of activation-inhibition processes, and that salience (priming) values, once assigned to information, exert carry-over effects to subsequent processing. The implications are that repeating the salience values for either attended or ignored information increases processing efficiency for the information, while changing salience values for the information decreases processing efficiency for the information. Importantly, the temporal
discrimination model highlights the importance of formatting information in a way that clearly marks it as familiar versus new. This model reminds us that ambiguous encoding can assign a temporal seniority to information that is not appropriate, forcing a greater use of executive discriminatory processes, which in turn make increased processing demands on the limited capacity of the WM system.

3.3.2 Priming in relation to classroom learning

In terms of effective learning, the activation-suppression model suggests that priming increases the level of activation above its normal resting state regardless of whether the information is to be attended or ignored, and that it does this prior to the information actually being presented (Rabinowitz & McAuley, 1990). According to this model, therefore, a distinction important to learning is that the availability of information during learning is not the same as its accessibility. Information is accessible on the basis of its level of activation, yet the availability of information remains the same regardless of its activation level. This distinction is notable because it highlights the importance of differential priming effects within the learning environment, thus urging educators to design units of work that account for these effects. The priming principle is not new to the field of educational psychology, but applying it intentionally to the area of instructional design means that a greater awareness of how to support the use of attentional strategies in the classroom is possible. This is important because of the close relationship that exists between priming and inhibition, wherein inhibitory demand acts to moderate the amount of mental effort experienced in relation to the attentional processing.

3.4 A review of cognitive inhibition in relation to processing constraint

Mental effort is considered important in this set of circumstances because research suggests that cognitive load, the amount of mental effort an individual invests in on-task learning, is affected by differences in the levels of activation and inhibition involved in the overall learning task (Mayer & Moreno, 2003; Paas, & van Merriënboer, 1993). According to cognitive load theory (Sweller, 1994; 1999; Sweller, van Merriënboer, & Paas, 1998), the way in which instructional strategies activate cognitive schemata determines how well the instruction is able to encapsulate information in a way that more effectively processes larger amounts of information, with positive schematic activation occurring when instructional encoding primes for the activation of essential (task-relevant) schemata (Mayer & Moreno,
Inhibition & Mental Effort: A Moderation Hypothesis
Chapter 3: Review of the Literature (part 2)

2003; Stanovich, 1990). Chi, Glasser, and Farr (1988) suggest that task-relevant schematic activation facilitates *automaticity*, the “obligatory” processing of complex schematic information, often as single “bits” of information. As automaticity increases, less inhibitory processing is required, due to the positive priming effects of essential schemata. This reasoning is echoed in cognitive load theory (Ayers, 2006), and presupposes that a significant relationship exists between inhibition and the amount of cognitive load associated with learning tasks.

In line with the thesis, a fundamental concern of cognitive load theory (CLT) is that the architecture of human information processing, in particular the relationship between working memory (WM) and long-term memory (LTM), largely determines learning efficiency (Asloun, Soury, Couillet, et al. 2008; Ayres & Paas, 2009; Sweller & Chandler, 1994; Sweller, van Merriënboer, & Paas, 1998). In light of this concern, the goal of CLT is to provide instructional design principles that facilitate learning in accordance with this cognitive architecture. Schnozt and Kürschner (2007) list the basic assumptions of CLT as including:

- a multiple memory store architecture,
- the notion that long-term memory consists of cognitive schemata,
- the construct of “cognitive load” (intrinsic, extraneous, and germane) as mental effort, due to the allocation of limited WM resources,
- the notion of ‘learning’ as an increase in expertise, due to schematic alterations in LTM,
- the concept of ‘understanding’ as the coherent, simultaneous processing of information elements at the WM level,
- the idea of “instructional consequences” - that instruction acts as an executive guide to assist in the development of relevant schemata for the learner.

The three distinct forms of cognitive load are particularly significant, in that each form contributes to mental effort in a different manner (Sweller, van Merriënboer, & Paas, 1998). *Intrinsic* load refers to the complexity of learning information, and is produced by the number of discrete elements that interact within WM during a learning task. Intrinsic load has been referred to as a type of “base” load (Kirschner, Paas, & Kirschner, 2009), because it is only amenable to change via long-term progressive learning or by extended task analysis. *Extraneous* load stems from the format of instructional encoding, and is viewed as an unnecessary impediment to learning that occurs due to poor design and organisation of the learning information. *Germane* load (also referred to as *essential* load) refers to the amount of mental
effort devoted to learning task-relevant information. This type of cognitive load is considered appropriate and desirable, as it consolidates schematic construction. Cognitive load theory has generally maintained that germane load contributes to the overall amount of cognitive load required to process instructional information, but recent research (Cierniak, Scheiter, & Gerjets, 2009) has disputed this. All three load types are important to instructional design, because they all connect the limited resources of WM to schema acquisition and/or schematic automaticity (Sweller, 2005; Sweller & Chandler, 1994). However extraneous load appears especially pertinent to the thesis, because it conjoins the influence of instructional encoding to inhibition as an executive WM function. It seems inherently logical that extraneous cognitive load requires increased inhibition, and yet this type of cognitive requirement may also be the most amenable to instructional control (Sweller & Chandler, 1994). The thesis therefore appears in harmony with the goals of cognitive load theory, which aim to identify and reduce the amount of extraneous load influences that derive from instructional design.

3.4.1 Instructional issues relating to cognitive load theory

The instructional issues relating to cognitive load theory (CLT) involve the degree to which instruction makes peculiar load type demands upon WM. According to Mayer and Moreno (2003), inefficient learning derives from instructional priming in which too much non-essential processing is required, that is, where the learner is required to perform significant incidental (task-irrelevant) processing and representational (short-term memory) holding in relation to learning. Non-essential processing requires increased inhibitory function because of the greater need to stop task-irrelevant and short-term information from interfering with the objectives of the learning task. In this understanding of processing constraint, mental effort represents the primary measure of cognitive load because cognitive load is able to represent the placement of specific learning requirements along a processing continuum, from non-essential processing to automatised processing. CLT is thus positioned in relation to inhibition because it highlights how differences in inhibition translate into differences in mental effort, due to the way instructional encoding can scaffold for greater or less automaticity. This is supported in that some cognitive load theorists (van Merriënboer & Sluijsmans, 2009) have suggested that an important part of what cognitive load measures is the level of inhibitory function required by a task or instructional encoding.
Cognitive load theory may also provide a rationale for understanding how differences in inhibition are linked to differences in achievement outcomes. From a cognitive load perspective this would occur because individual differences in inhibition moderate the amount of mental effort students’ experience during learning, contributing to variations in their ability to achieve set learning outcomes. The idea that inhibition moderates cognitive load represents the most fundamental proposition of the thesis. In line with this, several researchers have suggested that inhibition plays a central role in the way cognitive load is experienced (Mayer and Moreno, 2003; Sweller et al, 1998), further indicating that the relationship between cognitive load and inhibition deserves investigation as a specific factor related to classroom learning.

Table 3.2 overviews the instructional issues relating to cognitive load theory, by listing the various types of cognitive load along with their primary situational characteristics and possible solutions. Core aims are to reduce the need for incidental processing and the representational-holding of task-irrelevant information (which overloads WM limitations), and to encapsulate task-relevant information as much as possible (to reduce essential processing load). Cognitive load theory assumes that some learning environments impose greater cognitive demands than others, causing higher processing loads on the limited resources of WM. When this occurs various types of cognitive overload can result, such as split-attention, high-intrinsic loading, extraneous loading, redundancy, and de-synchronisation (cf. Mayer & Moreno, 2003; Sweller et al, 1998).

Table 3.2 Cognitive load theory: Types of processing demands made during learning

<table>
<thead>
<tr>
<th>OVERLOAD TYPE</th>
<th>SITUATIONAL ELEMENTS</th>
<th>TEACHING SOLUTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Split-attention effect</td>
<td>Attention split between two essential processing demands (say, visual &amp; written)</td>
<td>Off-loading – Teacher delivers a verbal narrative over the visual aid.</td>
</tr>
<tr>
<td>High intrinsic load</td>
<td>Information is rich &amp; pace of delivery is fast - essential processing requirements too great for learner to manage an active construction of meaning.</td>
<td>Segmenting – Use a distributed learning approach, breaking the information into smaller segments. Advance Organisers – Prime conceptual schema to increase automaticity &amp; thereby reduce WM load.</td>
</tr>
<tr>
<td>Extraneous load</td>
<td>Too much irrelevant material (background or procedural). Forces too much incidental processing &amp; takes away from essential</td>
<td>Use Prompts &amp; Cues – To help select &amp; organise the information. Condense – Remove or point-form the</td>
</tr>
</tbody>
</table>
Redundancy or Overlapping (Confusion) | Both essential & incidental processing required simultaneously, due to haphazard or disparate instructions. | Concept Integration – summarise related prior knowledge & concept-map the essential information, followed by extensions of ‘interesting’ extraneous information.

De-synchronisation (temporal, modal or proximal) | Separation of essential information, creating the need for too much representational holding while attempting to integrate information: Temporal (too much time between) Modal (too many formats used) Proximal (too much space between) | Synchronised Integration (for modal or proximal separation) – Present the various formats together to cut down on holding requirements (unless this creates a split-attention effect). Individualise – Use mnemonic aids to condense WM load, & try to match content type & quality to mnemonic strategy.

3.4.2 Measuring cognitive load

Paas, van Merrienboer and Adam (1994) described cognitive load theory as a multidimensional construct composed of two primary factors: causal factors related to the interactions that occur between the characteristics of the task and those of the learner, and assessment factors that pertain to interactions between mental load factors (a task-centred dimension composed of extrinsic environmental and task demands) and mental effort (a learner-centred dimension involving the amount of controlled processing used to accommodate mental load demands). They posited that an index for mental efficiency can be established by using mental effort as the measure of cognitive processing load, and performance as an index of effective learning. Mental effort can be measured by having the learner assign a numerical value, say on a Likert-scale, to the amount of invested mental effort they perceive to have experienced during a set learning task. Cognitive load research suggests that such measures, while subjective, are nonetheless reliable, and more sensitive than physiological methods, especially when used in conjunction with a dual-task assessment of WM (Ayres, 2006; cf. Ayres, & Paas, 2009; Paas and van Merriënboer, 1993). Measures of mental effort are useful to the thesis because learning efficiency could then be evaluated indirectly in terms of correlations occurring between the dual-task measure and the mental effort scores, and also more directly in terms of correlations occurring between the mental effort ratings and achievement outcomes. In both cases, the idea that mental effort and inhibition operate to influence learning outcomes is illuminated by understanding the role of priming.
3.4.3 Inhibitory function and cognitive load: The role of priming

A well known educational theorist in the area of information processing and learning is Juan Pascual-Leone (1970; 1980; 2000). His neo-piagetian theory of “constructive operators” offers a conceptual framework for investigating the impact of cognitive inhibition upon the learning situation in that it provides for what he terms the “dimension of interrupt operations”, that is, a measure of the degree to which instructional strategies either facilitate or mislead the learner in terms of priming for appropriate schematic processing during learning. Pascual-Leonne’s (2000) framework can be used to explain how priming relates inhibition to cognitive load in that he makes a distinction between the type of learning task demands made by the executive (M-capacity) inhibitory function (produced by misleading instructional priming), and by the non-executive (field of decay) inhibitory function (produced by facilitating instructional priming). Relevant to the current thesis is that whereas misleading priming places a higher cognitive load on the limited capacity WM system because it activates more non-relevant schemata (requiring greater inhibition), facilitating priming minimises attentional interruptions (requiring less inhibition). Thus, similar to the types of cognitive load envisioned by CLT, the notion that instructional organisation is a vehicle for priming the amount of inhibitory activity required for learning is again apparent.

Pascual-Leonne’s idea of processing facilitation, similar to the CLT notion of germane load, asserts that efficient schematic processing emphasises essential information-processing (thereby minimising incidental processing and representational holding, i.e., encouraging greater automaticity). Conversely, and similar to the concepts of intrinsic and extraneous load factors, his idea of misleading processing asserts that inefficient processing emphasises too much non-essential processing, involving significant incidental (task-irrelevant) processing and representational (short-term memory) holding in relation to learning. To clarify this part of the discussion, a visual depiction of Pascual-Leonne’s conceptualisation of priming as related to cognitive load theory is presented in figure 3.1.
This conceptualisation suggests that priming can be used to expand and strengthen the relationship between cognitive inhibition and mental effort, in that those instructional strategies which encode for both task-relevant and irrelevant priming will also scaffold for greater automaticity. This notion seems to be a fundamental common denominator in the way selective attention and cognitive inhibition are linked at the executive level, and suggests that strategies which are organised to make better account of the way schemata operate are also more able to overcome the capacity limitations inherent to the information processing system. Overall, this part of the review suggests that priming can provide a mechanism by which inhibition is able to moderate the amount of cognitive load experienced in relation to learning, especially the extraneous cognitive load that may be associated with instructional encoding. In this respect it is important to note that some theorists (e.g., Gerjets, Scheiter, & Cierniak, 2009; Schnotz & Kürschner, 2007) have indicated that the single greatest limitation of cognitive load theory is that it currently lacks an explanatory mechanism that is necessary and sufficient to the scope of its theoretical application. From this perspective, the thesis postulates that inhibition can provide a necessary causal mechanism for CLT - because it can explain the impact of cognitive load upon limited capacity processing, and that it can also provide a sufficient causal mechanism for CLT - because inhibition can explain how this impact occurs in relation to organisational priming.

3.5 Executive summary of literature review findings

Cognitive learning theory was reviewed initially, in relation to various cognitive approaches to instructional design. This part of the review served to highlight that cognitive approaches to classroom learning have largely emphasised instructional strategies targeting the use of salient, task-relevant information as the basis of instructional focus. This review has also suggested that WM functions relating to inhibitory processing have not been theoretically

![Figure 3.1 Proposed dimension of inhibitory efficiency.](image-url)
incorporated into the design of cognitive instruction to the same degree as those relating to task-relevant processing.

Information processing theory was then reviewed, because it is able to delineate many of the problems that learners experience in relation to learning, as well as to suggest appropriate strategies for dealing with these problems. Information processing theory was reviewed in terms of the relevance this theory has to the teaching/learning process. The finding of this review is that information processing theory is highly relevant to understanding learning at the classroom level. It is also suggested that information processing theory is valuable in that it allows testing and interpretation of the specific cognitive mechanisms considered by the thesis.

Schema theory was reviewed in relation to learning and to cognitive load. This part of the review examined the principles and concepts involved in schema theory. Importantly, these principles and concepts suggest that the way new information is organised in relation to existing knowledge influences the amount of inhibitory regulation required to process it. Schema theory thus offers a reasonable explanation as to how information organisation may affect the amount of cognitive load experienced in relation to processing. This further suggests that an important aspect of information organisation is how the information is primed for processing.

WM was reviewed in relation to learning by examining several proposed models of WM, as well as by reviewing cognitive and neuro-psychological research that has investigated WM function in relation to learning. Cognitive psychology has developed fairly detailed understandings of the processes involved in learning, and of the ways in which instruction influences these processes. Neuropsychology has developed well defined assessment procedures and imaging studies which help define the brain functions and cognitive skills needed in learning. When combined, these two disciplines provide a relevant and appropriate overview of the WM processes and functional skills that mediate the learning process. Overall, this part of the review indicated it is important that teachers design their instruction to support the brain-based functions of WM.

To better understand the role of inhibition as a specific aspect of WM function, research concerning the WM executive control processes was also reviewed. The executive processes control selective attentional processing, which is a key element in classroom learning. This part
of the review highlighted that selective attention involves executive control discriminations concerning the salience of information, in terms of whether the information is task-relevant and in need of further processing, or task-irrelevant and in need of being suppressed or inhibited from further processing. This interest is central to the thesis because of the underlying position that current cognitive pedagogies do not directly account for the inhibitory control process as a clear aspect of instructional design.

Inhibition was then reviewed by examining cognitive and neuropsychological models of inhibitory function, as well as by reviewing the research that has investigated inhibitory function in relation to literacy and numeracy. This information suggests that inhibition is an executive neuro-cognitive function, relevant to the effective operation of controlled attention and therefore an important element of instructional design. Cognitive learning theorists draw on the notion of CI to explain how the learner is supported to maintain attentional focus and how information is “forgotten”. Attentional focus is supported in that task-irrelevant information is inhibited from interfering with controlled attention during the learning process. Conversely, when inhibition is not effective, irrelevant information is allowed to interfere with attention and task-relevant information decays or becomes replaced. Effective inhibition is thus central to processing efficiency because it minimises the effects of task-irrelevant information on processing constraint. In terms of maximising learning, inhibition represents a key element to consider when designing instructional strategies across all key learning areas of the curriculum because it minimises the degree of cognitive load that is needed to maintain on-task processing.

Priming was examined in relation to inhibition by reviewing the main theories and concepts of priming. A review of this literature showed that theoretical constructs concerning priming can differ along several dimensions, and that these differences reflect the alignment of the priming construct to a particular model of attention. The review of this literature reveals, however, that regardless of attentional affiliation, a consensus exists that priming is capable of influencing the inhibitory function, due to the way it either activates or suppresses schemata.

Cognitive load theory (CLT) was then reviewed as an instructional design theory, and in relation to inhibition and priming. This part of the review highlighted the importance of schema theory in understanding classroom learning, and suggested that how information is organised affects learning, by placing different types of processing demands upon the WM system.
Research in this area reveals that the amount of cognitive load placed on WM during learning is affected by the degree to which the organisation and presentation of information primes for schema activation. In turn, this suggests that inhibition may provide the causal mechanism by which CLT is validated at the empirical level of investigation.

3.5.1 Conclusion and overview of the literature review

Overall, this review has suggested that an interaction occurs between the executive WM function relating to inhibition and the amount of cognitive load experienced during learning. This theoretical relationship is important to the thesis because it posits a novel factor to consider when designing cognitive approaches to classroom instruction. The overall framework presented consists of the principle of neuro-cognitive integration, the nature of executive WM processing, the role of inhibition with respect to information processing, the relationship between cognitive inhibition and cognitive priming, and how this relationship is connected to the theory of cognitive load.

The crux of this review is that executive WM processing, in particular inhibitory processing, is responsible for much of the cognitive load an individual experiences in relation to learning. This position is connected to cognitive learning theory in that the relationship between inhibition and cognitive load is viewed as being moderated by how the information relating to a learning task is primed for processing. From this position, the teacher’s use of priming is viewed as an important element in the application of cognitive learning theory. Priming thus forms the basis for designing instructional strategies that address the role of inhibition in relation to classroom learning. The theoretical framework presented here provides a necessary and sufficient rationale for the hypotheses relating to the thesis. The next chapter will present an overview and interpretation of this theoretical framework, in order to clarify the relationship between the thesis position and the methodology used to test the thesis.
CHAPTER 4: THEORETICAL FRAMEWORK

The identification and analysis of successful pedagogy is central to research in education, but is currently a foreign field to cognitive neuroscience (Goswami, 2004, p.1)

4.0 Introduction to the theoretical framework

This part of the thesis represents a distillation of the ideas and concepts discussed in the literature review chapters. The purpose of this chapter is to provide a summary overview and interpretation of the theoretical ideas and perspectives that underpin the thesis position. Central to this position is the notion that an interaction effect occurs between the executive WM function relating to inhibition and the amount of cognitive load experienced during learning. This theoretical relationship is important to the thesis because it posits a novel factor to consider when designing cognitive approaches to classroom instruction. The overall framework presented here is representative of information processing theory in that it includes the principle of neuro-cognitive integration, the construct of executive WM processing, and the role of inhibition. However this framework is also novel in that it posits a relationship between cognitive inhibition and cognitive priming, and connects this relationship to the theory of cognitive load.

The crux of the thesis position is that inhibitory processing, as an aspect of executive WM, is responsible for much of the cognitive load an individual experiences in relation to learning. This theoretical position is connected to cognitive learning theory because inhibition is viewed as a processing function capable of modifying cognitive load, based on how instructional information has been primed for processing. From this position, the teacher’s use of priming is viewed as an important element in the application of cognitive learning theory, because it helps determine the amount of inhibition required in relation to attentional processing. An appropriate understanding of priming is thus viewed as forming the basis for designing instructional strategies that address the role of inhibition in relation to classroom learning. This theoretical framework is presented in figure 4.1 as an inhibition X cognitive load model of attentional processing (note that T1 – T4 represents Teacher 1 – Teacher 4). This model provides a necessary rationale for the hypotheses relating to the
thesis, as well as providing the methodological direction and interpretive framework for the associated research.

Figure 4.1 An inhibition X cognitive load model of attentional processing.

4.1 Neuro-cognitive integration and executive processing

From a neuropsychological perspective, it seems logically intuitive that categorising and discriminating information requires some sort of overall processing function, or set of functions, that acts to coordinate and integrate the various processes involved. From the thesis position, it is suggested that how information is integrated - for example how the teacher performs task analysis and other forms of information organisation in relation to a learning task - affects the amount of mental effort required for cognitive integration, with integration appearing to involve several key cognitive and neurological processes associated with the WM system. As noted in the literature review, research suggests that a number of discrete cognitive and neuro-psychological processes are involved in cognitive integration, with some sort of executive or overall control mechanism serving to manipulate and
coordinate the information at a holistic level. Anderson (2000, p. 387) alluded to the relationship between integration and how the teacher has organised the information when he stated that, “analysis of instructional material into its cognitive components enables more effective instruction”. In this respect a fundamental tenet of the thesis is that WM executive processing, involving the integration of information from discrete brain areas and functional processes, provides the fundamental basis for learning.

As an example of this, learning in relation to written expression appears to involve the integration of information from at least two separate neurological pathways: A behavioural pathway encoding for direct motor task information, and a cognitive pathway encoding an independent abstract representation of this information (Berninger, 1999). Other research (De La Paz, Swanson, & Graham, 1998) has shown that intentionally directing the integration of information from several different pathways can produce significant improvement in written expression for students with learning difficulties, supporting the notion that multiple processing components may be at work during literacy-based learning. An interesting study in this respect is that of Matsuo, Nakai, Kato et al. (2000). In this study, two different motor-control hand movements, one similar to normal handwriting movements and the other quite different from handwriting movements, were shown to activate different areas of the brain, thus demonstrating a differential processing of information at the neuropsychological level. Of note is that the handwriting-like movements activated Broca’s area – an area of the brain dedicated to the processing of language - seemingly because they evoked phonological codes corresponding to that of normal handwriting.

In terms of numeracy and processing, it has been hypothesised that both semantic information and arithmetic difficulty interact during learning, forcing an even greater integration of information than language-based learning alone (Hegarty, Mayer, & Green, 1992; Rabinowitz & Woolley, 1995). It is evident that mathematical problem solving requires the processing of a variety of information types (Mayer & Hegarty, 1996; Riley, Greeno, & Heller, 1983), making significant demands on the limited capacity of the WM system and requiring executive integration of input related to both linguistic and arithmetic information (Bransford et al., 1996). This is because, at the neurologic level, semantic structures relating to the words involved in maths problems require processing in brain areas distinct to that of the arithmetic algorithms involved (Fuson, Carroll, & Landis, 1996). Thus,
students who are taught to develop their own word problems (Rudnistsky, Etheredge, Reeeman, & Gilbert, 1995), as well as those taught to consciously apply generalised semantic-based strategies to the solving of math problems (Verschaffel, DeCorte, & Vierstraete, 1999), both tend to perform better with respect to arithmetic problem-solving, because the semantic training assists the integration process. This suggests that the intrinsic nature of maths learning (in which both mathematical and semantic information are involved), is such that it requires the executive integration of information from distinct functional areas of information processing, in order to successfully problem solve within the domain of mathematical learning.

Denckla (1996) offers support to the idea of processing integration when she describes executive processing in terms of its overall functional roles. Connecting the notion of executive function directly to attention, Denckla emphasises that, “executive function is clearly a higher order, top-down domain” (p. 118). By this Denckla is referring to the fact that the brain is regarded as a series of interacting systems that work together in the acquisition and performance of tasks. Berninger and her colleagues (Berninger, Cartwright, Yates, Swanson, and Abbott, 1994; Berninger & Hart, 1992; Berninger & Richards, 2002) have suggested a similar understanding of executive processing, in that research coming from this camp stresses the importance of Luria’s (1973) concept of integrated brain systems as the basis for understanding both developmental literacy and language-based learning difficulties. Overall, information from neuropsychological research suggests that multiple processing functions form the basis for learning, emphasizing that a sort of neurological division of labour takes place which allows the learner to exercise both discretion and integration in relation to learning objectives. The current thesis is especially interested in how one aspect of this division, the inhibitory function, exerts a distinct influence on the overall process of integrated learning. This interest is also supported by research from the area of cognitive psychology.

4.1.1 Cognitive models of integration

Within cognitive learning theory it seems that many cognitive approaches to learning have adapted Baddeley’s (1986; 2001) model of WM. Baddeley’s revised model (2001) aims to better reflect neuropsychological findings, and is based on the notion of a modular cognitive architecture (i.e., an architecture in which distinct cognitive processes are derived
from structurally dedicated processing components). Key characteristics of the modular model are that information is encapsulated (i.e., inputs are compartmentalized and dedicated), that the processing occurs in a fast, serial fashion, and that the processing is limited in capacity. The overall emphasis of this model is that WM, in particular the executive WM processes, act to differentiate and integrate information in relation to task outcomes and learning achievement.

With respect to classroom learning, various models of writing reflect Baddeley’s concept of a distinct, modular WM system. For example, Kellogg (1996) applied Baddeley’s (1986) model to the writing process, to suggest three separate cognitive elements involved in writing that correspond to Baddeley’s modular components: A verbal formulation element (linked to Baddeley’s visuo-spatial sketchpad), a monitoring element (linked to Baddeley’s phonological loop), and an execution element (linked to Baddeley’s central executive). Kellogg also added a recursive processing loop between verbal formulation, monitoring, and execution, highlighting processing integration as a fundamental aspect of the writing process.

Borkowski, Estrada, Milstead, and Hale (1989) have applied Baddeley’s model of WM to the notion that many learning problems are the result of executive WM processing deficits. In their understanding of skill achievement, metacognition (knowing how one thinks, including one’s cognitive strengths and limitations) provides the ability to self-regulate, via the integration of conditional strategy knowledge and general strategy knowledge. Borkowski et al. claim that by developing conditional and general strategy knowledge successfully, children also improve their self-efficacy (sense of competence and ability to attain goals, cf. Bandura, 1997). Taken together, a strong sense of confidence and clear repertoire of strategies allow strategic metacognitive planning of how to best approach learning for the child. This approach to skill development thus seems to view self-regulated learning as the product of metacognitive integration, involving the executive functions of WM.

In a similar manner, Berninger and Swanson (1994) have suggested a developmental model to explain the acquisition of writing skills in relation to learning. They proposed that processing automation (where the processing of well-rehearsed procedural information becomes progressively automatic in the way it is activated and processed) occurred for most
children during the primary school years, and that this cognitive achievement laid the
foundation for the emergence of more advanced writing skills such as text revision, advanced
planning, and the expansion of WM capacity. Here the increase in WM capacity is viewed as
resulting from the progressively automatised nature of writing skills, requiring – with equal
progressiveness - less executive processing to control the writing process. Although this
developmental model is not a direct representation of Baddeley’s modular WM construct, it
nonetheless incorporates a similar, compartmentalised notion of executive processing,
wherein developmental learning is characterised by component processing functions that
become increasingly integrated over time.

It is of interest that Baddeley’s 2001 model tends to support the positions of both
Denkla and Berninger, by acknowledging the need for an overall integrative component for
WM (i.e., Baddeley’s episodic buffer). In this respect it appears that Baddeley’s conceptual
model of WM, as well as findings from cognitive psychological research, suggest that the
processing of learning-related information occurs at various levels and involves distinct
processing functions, which, in turn, require some sort of overall control mechanism to
integrate the information into a coherent and meaningful understanding. Indeed, the evidence
from both neuropsychological and cognitive psychological research suggests that WM is
composed of distinct processing components or functions, which obtain from anatomically
separate areas of the brain. For the current thesis, this highlights the notion that learning
manifests from the integration of various and distinct neuro-cognitive processes related to
attention. In line with the literature review, the thesis is particularly interested in how the
relationship between information activation and information inhibition operates to support the
integration of these processes. In order to further elucidate this aspect of the thesis position, a
closer look at the relationship between activation and inhibition is required.

4.2 Activation and inhibition as the controllers of attentional integration

As discussed in the literature review, the more contextualized and discriminatory
aspects of WM processing are generally associated with the WM executive control
mechanisms, and are considered important to classroom learning because they regulate
selective attention. Indeed, it is this ability - to simultaneously activate and inhibit
information – that seems to allow WM to process information more or less automatically for
much of what constitutes learning (Mayer & Moreno, 2003; Paas & van Merrienboer, 1993; Sweller, 1994).

Concerning the executive control functions, Pickering and Gathercole (2004, pp. 394-395) noted the following:

The model (of WM developed originally by Baddeley and Hitch [1974], and extended by Baddeley [2000]) consists of a central executive linked directly with three other subsystems: the phonological loop, the visuo-spatial sketchpad, and the episodic buffer. The central executive is a flexible system responsible for the control and regulation of cognitive processes such as the coordination of multiple tasks (Baddeley, Della Sala, Papagno, & Spinmler, 1997), shifting between tasks or retrieval strategies (Baddeley, 1996), and selective attention and inhibition (Baddeley, Emslie, Kolodny, & Duncan, 1998).

It is important to understand the relationship between activation and inhibition because executive control problems, generally involving selective attention and inhibition, are considered one of the primary cognitive deficits associated with poor learner outcomes, and often linked with disorders that involve abnormal or defective information processing, including ADHD (Barkley, 1997; Montague & Warger, 1997; Schweitzer, 1999; Tannock, Ickowicz & Schachar, 1995), autistic spectrum disorder (ASD) (Jarrold et al., 2000), some learning disabilities (Dodge, 1993; Dweck, & Leggett, 1988), reading disorders (Berninger & Colwell, 1985), and even emotional disturbance (Hallenbeck & Kauffman, 1996; Handwerk & Marshall, 1998). Within the learning environment it is therefore important to understand not only the general relationship that exists between learning and WM capacity, but also how the executive WM processes, which control the activation/inhibition functions of selective attention, might also affect learning.

4.3 The role of inhibition in relation to learning

With respect to the thesis, it is particularly important to note the role of inhibition in relation to selective attention. As noted in the literature review, understanding inhibition is important because students are unable to attend to all the information that confronts them in the daily classroom and thus have to allocate attentional control selectively, requiring the ongoing suppression of task-irrelevant or distracting information in order to achieve learning outcomes (cf. D’Arcangelo, 1998, Wolfe & Brandt, 1998). By suppressing task-irrelevant information, inhibition supports the learner to selectively attend to information salient to the
Inhibition is essential to learning because it helps regulate the performance of important learning-related tasks, such as reading, studying, retrieving information during a test, problem-solving, and decision making, by assisting with the selective suppression or removal of task-irrelevant information from memory during learning. Indeed, some researchers suggest that inhibition actually provides the basis upon which selective attentional focus is structured (Bjorklund & Harnishfeger, 1990; Davies, Taylor & Jones, 1984; Harnishfeger, 1995; Karatekin, 2004; Pascual-Leone, 2000), supporting the thesis contention that inhibition represents a distinct element to consider when designing instructional strategies.

In applying WM knowledge to the classroom, Gathercole (1999) suggested that a cognitive understanding of learning in relation to information processing reveals three important correlates of executive control: processing efficiency (mainly the speed of processing information), attentional capacity (the amount of information processed), and task-switching ability (the ability to switch effectively from one task to another). All three areas involve the ability to focus selectively on task-relevant information, while at the same time inhibiting distracting or non-relevant information, in order to maximise the processing of task-relevant information during learning. However task-switching may require particular use of inhibition, to switch efficiently from one set of attentional cues to another. The thesis asserts that for task-switching, inhibition provides the means by which the activation of task-irrelevant information is cognitively interrupted.

At the classroom level, switching between tasks occurs whenever situational changes to the learning activity are required, for example when alternating between arithmetic problems (addition, subtraction), when rules governing the learning activity are changed, when learning goals are shifted, when the mode of processing is changed, or when complex processing is required. During switching, even between simple yet distinct activity changes, the task-relevant features of information have to be attended to differentially. This requires that attention be divided, at least in the short-term, and that the limited capacity processing system perform a minimum of two tasks at the same time. In relation to classroom learning, task-switching thus contains a particular processing cost, and the measure of that cost appears to be the amount of inhibitory control needed to maintain on-task attentional focus in the face of task-irrelevant and task-ambiguous information. Effective inhibition is thus
central to processing efficiency because, overall, it minimises the effects of distracting information on processing constraint. In this respect several researchers suggest that it is actually the inhibitory function that increases during cognitive development, formatting the developmental progression of WM capacity itself (Bjorklund & Buchannan, 1989; Dempster, 1992; Harnishfeger & Bjorklund, 1994; Swanson, 1999).

According to the thesis, the activation/inhibition balance can become skewed in response to poor instructional formatting, which forces the learner to task-switch inadvertently, as they seek to select the most salient task-relevant information within an ambiguous attentional milieu. The relationship between activation and inhibition is thus central to the thesis because it stipulates that the control of selective attention is dependent upon the type of instructional formatting the teacher brings to the learner. In turn, because this relationship operates within a limited set of processing resources, the inhibition X cognitive load model of attentional processing suggests that poor instructional formatting exerts a greater demand on inhibition because it primes for irrelevant attentional processing. For this reason the thesis also postulates that an important relationship exists between inhibition, priming, and cognitive load.

4.4 Inhibition, priming, and cognitive load

4.4.1 Inhibition and priming

According to the inhibition X cognitive load model of attentional processing, the inhibitory influence on cognitive load stems from the way in which learning information is organised by the teacher. As noted in the literature review, research indicates that the way in which information is organised has a significant effect on how individuals are “primed” for processing it, and that priming can exhibit both a positive bias (facilitating information access), or a negative bias (impeding information access). Important to the thesis, negative priming is a highly robust processing phenomenon, and, according to Neill, Valdes and Terry (1995), at the classroom level can result from many different factors of instructional design that help to organise on-task learning, including lexical ambiguity, the use of homographs, how the teacher uses intra-categorical information in relation to advance organisers or classroom questioning, and how lexical decision tasks are organised in terms of early learning or in terms of those areas of learning that are rich in jargon or technical terms.
Thus, the inhibition X cognitive load model of attentional processing suggests that how the teacher organises instructional information is important to the amount of cognitive load experienced in relation to learning.

As outlined in chapter 1, and discussed in the literature review, priming is at the heart of efficient instructional encoding because of the way it activates cognitive schemata. However, because activated schemata are accessed via the selective attentional processes associated with the executive control functions of WM, priming involves the use of inhibition to suppress the activation of irrelevant and partially-relevant schemata, e.g., as with task-switching. There is thus a cognitive cost to negative priming, and this is generally experienced in terms of the amount of cognitive load or “mental effort” an individual experiences in relation to the learning.

4.4.2 Inhibition and cognitive load

Because of these priming effects, and especially negative priming, inhibition also has a strong relationship to cognitive load. Cognitive load is considered important in these considerations because research suggests that the amount of cognitive load an individual experiences in relation to an on-task activity is affected by differences in the levels of activation and inhibition involved in a learning task (cf. Mayer & Moreno, 2003; Paas, & van Merrienboer, 1993; Sweller, 1994). As noted in the literature review, the way in which instructional strategies activate cognitive schemata determines how well the learner is able to effectively process larger amounts of information, because task-relevant schematic activation facilitates automaticity. As automaticity increases, less inhibitory processing is required, due to the positive priming effects of essential schemata. Thus there is reason to expect that a significant relationship exists between inhibition and cognitive load.

In this respect Mayer and Moreno (2003) posited inefficient learning as deriving from instructional priming in which too much non-essential processing is required (involving incidental processing and representational holding). Non-essential processing requires increased inhibitory function because of the greater need to stop task-irrelevant and short-term information from interfering with the objectives of the learning task. The inhibition X cognitive load model of attentional processing thus positions cognitive load in relation to inhibition because this positioning highlights how differences in inhibition translate into
differences in mental effort, due to the way instructional encoding can scaffold for greater or less automaticity, that is, due to the way instructional encoding can assist or detract from the integrative process.

4.5 An inhibition X cognitive load model of teaching and learning

On this basis the thesis proposes that cognitive inhibition functions to moderate the amount of cognitive load experienced in relation to learning. This is viewed as important to the area of instructional design because extraneous cognitive load, in particular, can result from instructional encoding that is ambiguous or conflicting, forcing the WM system to work harder to sequence information in a relevant and meaningful manner. The mechanism for this moderation seems to derive from the phenomenon of priming, and it is important to note that both facilitating priming (Marcel, 1983) and negative priming (Tipper, 1985) have been shown to inhibit information, as well as slow the processing of relevant information.

Important to the proposed moderation process, inhibition, like all WM functions, varies in quality from individual to individual, producing a wide range of individual differences in terms of the ability to process distracting or conflicting information. Although additional factors relating to individual differences can also impact on the processing outcomes for students (familiarity with subject matter, the automaticity of specific content information, etc., cf. sections 1.12 – 1.15; 5.18 – 5.20; 5.26 – 5.27; 7.36 – 7.39 of the thesis), this marks inhibition as an important factor in determining how individual differences in cognition affect the learner’s ability to process instructional information effectively. It also lays the foundation for investigating the role of inhibition as an influence on cognitive load.

4.5.1 Summary and overview of the theoretical framework of the thesis

This chapter has proposed a particular theoretical interpretation of the relationship between inhibition and cognitive load, whereby cognitive integration necessitates an executive control mechanism to account for the effective processing of information in relation to learning. This mechanism must simultaneously activate task-relevant information and inhibit task-irrelevant information, thus utilising inhibitory function as part of the selective attention process. At the classroom level, a key processing feature of the inhibitory function appears to be how the information has been organised and encoded, with information priming representing a core feature of this encoding. Positive priming can
facilitate less inhibitory requirements for learning, because it supports greater automaticity in the processing. Yet negative priming requires a greater need for inhibition, because it requires more schematic suppression. Importantly, when more inhibition is needed to process the information, the learner experiences higher levels of cognitive load. The theoretical framework presented here thus posits an interaction effect between inhibition and cognitive load, wherein inhibitory demand acts to moderate the amount of cognitive load experienced in relation to a learning task. It is suggested that, due to the limited processing capacity of WM, the interaction between inhibition and cognitive load will also contribute significantly to individual differences in terms of achievement outcomes.

The inhibition X cognitive load model of attentional processing presented in this chapter depicts the moderation effect of inhibition in relation to classroom learning. Note that in this depiction, the instruction received from different teachers (T1 – T4) is connected to learning outcomes via the conditioning of attentional processing by interactions that take place between inhibition and cognitive load. In particular, the amount of inhibition required to process instructional information is viewed as moderating the amount of cognitive load experienced in relation to learning, producing individual differences in the learning outcomes themselves. Thus the inhibition X cognitive load model of attentional processing hypothesises that individual differences in inhibitory ability will affect the amount of cognitive load experienced in connection to learning, and thereby influence the range of achievement outcomes attained within a normally distributed group of learners. The next chapter will detail the methodology by which this model of inhibitory effect is tested.
CHAPTER 5: METHODOLOGY

Teachers are entrusted with a noble profession – educating minds. It is ironic, therefore, that teachers are given no professional preparation about the brain. (Berninger & Richards, 2002, p. 3).

5.0 Research design

This chapter details the methods used to investigate three sets of relationships about learning, as posed in this study:

a) how the learner’s ability to inhibit irrelevant information affects the amount of cognitive load they experience in connection to their learning,

b) whether the relationship between inhibition and cognitive load is affected by the instructional encoding of information, and

c) whether the interaction between inhibition, cognitive load, and instructional encoding affected achievement outcomes for the learner.

In order to investigate these relationships, five cognitive functions needed to be identified and measured:

a) Individual WM function – (IV) a preliminary screening to establish developmentally appropriate WM functioning for the student participants.

b) Individual inhibitory function – (IV) a preliminary screening to establish specific inhibitory ability for these same students.

c) Perceived cognitive load in relation to learning tasks – (DV) to establish individual cognitive load differences for the students.

d) Teachers’ use of instructional encoding – (DV) to establish differences among the participating teachers, in terms of the way they each encoded instructional information.

e) Student achievement outcomes – (DV) to establish whether a connection exists between cognitive load, instructional ambiguity, and achievement.

At the heart of the methods used to test the thesis stands the relationship between inhibitory differences and cognitive load for a group of Year-8 students. Student WM functions relative to representational holding (short-term store), and problem-solving ability (accuracy in solving math problems) were determined for the students, because
these functions indicated whether the students were processing information at a developmentally appropriate level. The ability to process conflicting or distracting information was also determined for the students, and self-reported measures of cognitive load were obtained in relation to instruction the students received from four different teachers who taught them in common. Of particular interest was whether those students identified as less able to inhibit distracting information would generally rate the instruction as requiring higher levels of mental effort than those students identified as more able to inhibit distracting information. Also of interest was whether these ratings would vary or remain stable across the different teachers, and, if varied, whether the amount of cognitive load reported by the students would correlate with the instructional encoding assigned to the teachers, as well as with the achievement outcomes received from the teachers.

Figure 5.1 gives a conceptual overview of how the relationships between inhibition, cognitive load, instructional encoding, and achievement are understood to interact within the study. Note that this conceptualisation represents an application of the inhibition X cognitive load model of learning presented in chapter four of the thesis, extrapolating the effects of this interaction from the perspective of the individual learner’s inhibitory ability. The underlying principle in both representations is that inhibition is expected to modify the experience of cognitive load, in response to various instructional inputs, by making differing demands on the executive attentional processing functions of WM. Thus moderation, rather than mediation, is considered the more valid interpretation of the relationship between cognitive inhibition and cognitive load, because inhibition is being viewed as influencing the allocation of the executive WM functions relating to attentional processing, without actually altering the overall capacity of WM, or the functions themselves.

Attentional processing is, therefore, viewed as being modified by intrinsic factors that relate to the ability of the learner (inhibition X cognitive load), and by extrinsic factors (instructional encoding) that are modifiable by the teachers. An interaction effect (inhibition X cognitive load X instructional encoding) created from these factors is expected to contribute to the range of learning outcomes achieved under the different teachers. Thus, it is expected that individual differences in student inhibitory function will
ultimately affect the range of individual differences that occur for achievement outcomes, due to the interaction between inhibition and cognitive load. This conceptualisation underscores the notion that inhibitory function is particularly important to the issue of extraneous cognitive load, as envisaged by cognitive load theory.

Figure 5.1 Conceptual overview of generalized study relationships.

5.1 Methodological rationale

The methodology for this research was based on an interdependent transactional model of information processing, as represented in figure 4.1 (chapter 4) of the thesis. This model posits interactions between specific WM functions that affect the way the learner processes information and pedagogical factors that assign certain types of cognitive tasks to the learner. The model thus views learning as the product of complex and interactive cognitive processes that manipulate instructional information according to individual information processing ability, in order to produce the individual’s learning outcome.

A within-group, quasi-experimental methodological design was used to test this model, within the context of an actual school setting. As Ray (2004) noted, this type of design is useful for discovering the effects of a particular event, relationship, or difference for members of a common group. This type of design has been used to address questions derived from a particular theory as applied within a specific context (Gall, Gall, & Borg, 2007), as was the current study. Using the vast body of knowledge previously developed
concerning information processing theory and cognitive load theory (which has to do with how information processing affects, and is affected by, instructional design), the quasi-experimental approach provided a means for organising the questions and hypotheses to be addressed, data to be collected, and interpretations to be made.

An important principle of this approach is its use of inter-rater reliability to establish a measure of external validity for the research findings (Creswell, 2008). This is important to the current study because it is difficult to establish external validity for research performed within the complexity of authentic, “real world” learning contexts, and especially where the participants represent mixed ability levels and come from highly diverse backgrounds, as in the present study (Burns, 1997). Similar to the concept of triangulation, inter-rater reliability refers to the use of two or more raters in a research study, to establish the level of agreement between them on a specified set of observational criteria. Highly similar ratings between different raters represent greater consistency in the application of the criteria being rated. In turn, this can be used to indicate that the criteria themselves display a degree of objective validity in terms of what they are attempting to measure.

To control for reliability in the current study, classroom instructional information was rated by several independent observers: The researcher rated this information, the classroom teachers rated one another on the same criteria, a research assistant rated the teachers on it, and a non-teaching staff member of the School (a research administration staff member) also rated the teachers on it. Reliability coefficients for these observations are detailed in section 5.4. Validity and reliability issues for the particular WM and inhibitory measures used in the study were established on the basis of their concordance with established norms for the tests used, and are also detailed in section 5.4.

The quasi-experimental methodology allowed the research to study learning-related behaviours and perceptions within a natural, authentic context, whilst still providing precise measures of inhibition and cognitive load. This consideration is important because it allows for the establishment of what Burns (1997, p. 325) calls the “typicality or atypicality of a phenomenon”, that is, it underpins the study’s ability to generalise the outcomes to some degree. The use of a quasi-experimental methodology
allowed greater confidence that the study findings could be applied to the setting in a more general manner.

This design was applied to a group of Year-8 students attending a local private high school. The sample characteristics for this group are discussed below, in section 5.2.1. Of importance is that the participating student sample in the study included 70% of the entire year-8 population for the school, and that the parental demographics for these students reflected that of the normal community population, spanning unemployed persons, one or both parents studying at University, unskilled and skilled workers, and professionals. Overall family demographics included nuclear, mixed, and single parent situations, as well as low and middle socio-economic positions. These overall demographics represented a broad spectrum of white European, Australian Indigenous, and several ethnic group affiliations. Thus, although the population validity (Bracht & Glass, 1968) for the sample is convenient, an assumption of normality may yet be made, based on the fact that the total demographic characteristics of the sample resemble the wider School and community populations. This suggests that the findings of this research are relevant to the targeted population of interest.

5.2 Research setting

The study took place in a moderate-sized, coeducational private sector High School, located in the Northern Rivers area of New South Wales. The student population for this School was approximately 1,100, with a fairly even distribution of male and female students, teachers drawn from various backgrounds and characterised by a large range of teaching experiences, and students from diverse family backgrounds. All study information was collected on site at the School. The target group for the study was middle-school (year-7 to year-9) students and their teachers. The results of the study are aimed at teachers, educational psychologists, and other instructional designers interested in improving cognitive approaches to the teaching and learning of middle-school learners.

5.2.1 Study participants

Participants in the study comprised 114 Year-8 students (54% female, 46% male), with an average age of 13.83 years (SD = 0.40); and 4 teachers (1 female) with an average
of 15.25 years teaching experience (SD = 10.40, range = 2 to 27 years). Although 118 students had agreed to participate in the study originally, three were excluded from analysis because they displayed significantly low WM scores on the measures of interest, and one was excluded because she displayed exceptionally high WM scores on these same measures. The data from these students was excluded in order to control for the influence of outliers in the study analyses.

The participating teachers represented a sample of convenience, being the largest group of local teachers who taught a Year-8 cohort in common. All agreed to participate in research investigating the relationship between instruction and student cognition. Subjects being taught by the teachers included English, Science, History (female), and Math. Teacher number one (T1) taught English and was the youngest teaching participant, being a 24-year-old male with 2 years teaching experience. The science teacher (T2) was a 48-year-old male, with 18 years teaching experience. The History teacher (T3) was the most experienced teaching participant, being a 58-year-old female with 27 years teaching experience. The Math teacher (T4) was a 38-year-old male, with 14 years teaching experience. Average age of the participating teachers was 41.75 years (SD = 14.62 years, range = 24 – 58 years). Figure 5.2 displays an overview of the teaching experience and age for these teachers.

![Figure 5.2 Participating teachers by teaching experience and age.](image)

The students participating in the study were all being taught by these teachers in the natural course of events (i.e., also convenient). However, the 114 participating students represented a significant percentage (70.4%) of the overall number of Year-8 students.
attending the school (162 Year-8 students attended this school overall). Using a unified Year-8 cohort meant that the research was able to maintain a similar developmental focus across the participating student population. As noted earlier, the demographics for these students displayed normal population characteristics, including a wide range of SES backgrounds, ethnic diversity, differences in educational backgrounds, and a normally distributed range of prior achievement outcomes. Thus, the focus of the investigation was considered coherent enough to progress with the research.

### 5.2.2 Procedures

The procedures used in this study were designed to investigate four areas of the learning situation viewed as operating in an interdependent and reciprocal manner: Student information processing, the experience of cognitive load, instructional encoding, and achievement outcomes. Because of the scope of the investigation, including both intra-area as well as inter-area relationships being tested, it is necessary to perform multiple analyses, in order to separately test the instructional encoding elements (cf. pp. 6.6 – 6.7). In addition, because of the varying reliability ratings for these elements, as well as the fact that the thesis represents a pilot study into the overall relationships posited, it is also important to explore all possibilities in terms of analysis and interpretation. Thus, it is important to note that the investigative procedures for the thesis are designed to consider various possibilities in terms of exploring the outcome findings for the study, as detailed in the rest of this chapter.

The relationship between student information processing and experienced cognitive load was investigated by measuring individual student inhibitory ability (using a Flanker Task), and then having the students’ rate (see Appendix A) how hard they had to work mentally in order to process instructional information under the four participating teachers they had in common. A positive relationship between students’ inhibition scores and their experience of cognitive load would indicate a generalised relationship between inhibition and mental effort. That is, more able-to-inhibit students were experiencing less mental effort in relation to their classroom learning, while the less able-to-inhibit students were experiencing greater mental effort in relation to the same classroom learning.
Additionally, it was expected that the way instructional information was encoded would differ among the four teachers, and affect the amount of cognitive load experienced by the students. Mayer and Moreno (2003) previously clarified the possible impact of such encoding differences by defining inefficient learning as the product of instructional encoding that requires too much non-essential processing, leading to excessive cognitive load being made upon the WM system. Other elements of the literature (Harnishfeger, 1995; Neil et al, 1995) suggested that non-essential processing could be caused by ambiguity in the way information is encoded, and that ambiguous encoding produces greater cognitive load demands because more inhibition is required to suppress irrelevant or conflicting information during the learning (Paas, van Merrienboer, & Adam, 1994; Sweller, van Merriënboer, & Paas, 1998).

In accordance with the notion of encoding ambiguity, preliminary information was gathered to identify various types of ambiguous instructional encoding. An open-ended interview question was posed to determine students’ pre-study understanding of how the teacher might distract or confuse them during instruction. Each student was asked, “What sorts of things do your teachers do, that might make it more difficult or harder to understand what they want you to learn?” In response to this question, four main aspects of “instructional ambiguity” were identified in relation to the students’ classroom learning experiences:

1. Learning was more difficult when the teacher presented relevant and irrelevant information without any distinctions being made,
2. Sometimes the teacher asked questions in a way that gave irrelevant or distracting “cues” to the students (confusing them),
3. It was confusing when the teacher used words that could refer to or mean several different things, and
4. It was distracting when the teacher used technical or topic specific (jargon) words without clearly establishing the semantic meaning of these words.

These four aspects were used to form the instructional ambiguity encoding elements as detailed in Appendix B. These elements were then utilised to observationally rate instructional ambiguity in relation to sixteen (16) individual lessons for each of the
participating teachers. The ratings were averaged for each of the participating teachers and used to represent basic differences in the way individual teachers were encoding for ambiguity in their instructional delivery.

In accordance with the inhibition X cognitive load model of learning, it was also expected that individual differences in the students’ inhibitory function and experience of cognitive load would be able to predict learning outcomes as achieved under the different teachers. Confirmation of this expectation would indicate that inhibition, via the moderation of cognitive load, was exerting a significant effect upon the students’ ability to achieve the set learning outcomes. This relationship was tested by using a series of one-way Analysis of Variance (ANOVA) tests to see if interactions were occurring between student achievement outcomes (measured as a percentage of the total achievement possible for each teaching area [100%]), the student’s inhibition scores, and their cognitive load scores (these analyses are detailed further in section 5.4).

An overview of the study’s procedures is presented in table 5.1, by area of investigation and phase of research. Note that a peer reviewed report was generated and publically presented for each area of the research, as listed at the end of each column. These reports generated a considerable amount of professional feedback for the research as it progressed, and that feedback is acknowledged here as an important source of ongoing, reflexive consideration and collaborative knowledge building.

**Table 5.1 Overview of research study procedures**

<table>
<thead>
<tr>
<th>Area 1: Student Information Processing</th>
<th>Area 2: Instructional Observations</th>
<th>Area 3: Analysis and Interpretation of Achievement</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Informed Consent gained from Principals</td>
<td>Observational criteria developed (Appendix B) and discussed with teachers and other observers.</td>
<td>Statistical model developed for data analysis, based on the General Linear Model (GLM, see Appendix C)</td>
</tr>
<tr>
<td>• Informed Consent gained from Teachers</td>
<td></td>
<td>Analyses made on relationships between inhibitory function, cognitive load, instructional ambiguity, and achievement outcomes.</td>
</tr>
<tr>
<td>• Informed Consent gained from Parents &amp; Students</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teacher interviews conducted to explain study and develop collaborative understanding of the study instruments &amp; procedures.</td>
<td>Begin collecting data from 16 Classroom Instructional observations for each participating teacher, using the criteria from Appendix B. (Minimum of 2 observers used for each observation).</td>
<td>Complete Classroom Instructional observations.</td>
</tr>
<tr>
<td>Student interviews conducted to explain study and develop a clear understanding of the central role played by student testing &amp; student cognitive load ratings in the study. Instructional ambiguity elements established.</td>
<td>Student Cognitive Load (CL) Ratings Collected: All participating students performed 16 CL ratings for each of the participating teachers</td>
<td>Study data analysed and interpreted in relation to the inhibition X cognitive load model of attentional processing.</td>
</tr>
</tbody>
</table>
5.3 Research questions, hypotheses, and operational measures

The purpose of the study was to assess the impact of inhibitory ability on cognitive load and to determine whether this impact, in turn, interacted with instructional encoding to influence achievement outcomes. To make these determinations, the following research questions needed to be addressed:

1) Are individual differences in inhibition apparent, and do they affect the way students experience mental effort at the classroom level?

2) Do the students’ experience of mental effort vary across the different teachers from whom they receive instruction?

2.a) If so, does this variation correlate with the elements of instructional encoding specified as relevant to ambiguity in the literature review and confirmed in preliminary student interviews?,

3) Do inhibition and mental effort, or both; appear to affect the types of learning outcomes the students achieve under the different teachers?

The theoretical nature of this inquiry also lends itself to the pursuit of several specific hypotheses in relation to these questions. Table 5.2 gives an overview of these hypotheses, along with the operational measure for each hypothesis.

The second hypothesis represents the foundational assumption of the thesis, that inhibition modifies the experience of cognitive load. However this hypothesis is based upon a counterintuitive relationship that requires some clarification. The second hypothesis predicts a positive relationship between inhibition (CI) and cognitive load.
yet the scores for these variables actually represent oppositional values. That is, higher CI scores represent less inhibitory ability, and higher CL scores represent greater mental effort. Hence, this inverse relationship means the less able inhibitors are expected to experience greater mental effort in their learning (and thus obtaining higher scores for both CI and CL); and the more able inhibitors are expected to experience less mental effort (and thus obtain lower scores for both CI and CL).

5.3.1 Logic of the hypotheses

Each of these hypotheses was conceptualised on the basis of prior knowledge and evidence about information processing in relation to learning. The first hypothesis predicts that the measure of WM used in the study (the OSPAN, see section 5.4) is a valid predictor of the students’ ability to achieve overall learning outcomes. Various prior studies have indicated that individual differences for WM function are highly correlated with individual differences for learning outcomes (Berninger, 1999; Bjorklund & Buchannan, 1989; Cariglia–Bull & Pressley, 1990; Conway et al., 2005; Tuholski, Engle, & Baylis, 2001).

The second hypothesis predicts a more particular outcome in relation to the executive functions of WM. Specifically that a significant relationship will exist between student inhibitory ability and the amount of mental effort experienced by the student in relation to their learning. To the author’s knowledge, this relationship has not been explicitly tested. The second hypothesis for this study also seeks to “marry” two related notions: First, the notion that inhibition plays an important role in both development and learning, as widely indicated in the literature (Bjorkland & Harnishfeger, 1990; Burgess & Simpson, 1988; Halford, 2002; Harnishfeger, 1995; Harnishfeger & Bjorklund, 1994; Passolunghi, Cornoldi & de Liberto, 1999; Rothermund & Wentura, 2004; Shimamura, 2000; Verschaffel, DeCorte, & Vierstraete, 1999). Second, the idea that at least part of the cognitive load experienced in relation to learning stems from inhibition (Hooper, Swartz, Wakely, de Kruif, & Montgomery, 2002; Kalyuga, Chandler, Tuovinen, & Sweller, 2001; Kane, Bleckley, Conway, & Engle, 2001; Montague & Wager, 1997; Paas & van Merrienboer, 1993; Sweller, 1994; Sweller, van Merrienboer, & Paas, 1998). The concept of cognitive load thus provides one measure of the demands made on WM processing.
constraint by learning tasks, with part of this demand involving the degree to which the learning task requires inhibition.

The third to sixth hypotheses for this research are concerned with influences that determine the relationship between inhibition and cognitive load. These hypotheses are based on evidence from two different sources involving information about student priming and schema activation: First, priming studies have suggested that the processing of task-irrelevant information requires greater use of inhibition (Barrouillet, Fayol, & Lathuliere, 1997; Bjorklund & Buchanan, 1989; Bjorkland & Harnishfeger, 1990; Brown, 1979; Burgess & Simpson, 1988; Corbetta, Shulman, Miezin, & Petersen, 1995; De La Paz, Swanson, & Graham, 1998; Dempster, 1991; Dempster & Brainerd, 1995; Fox, 1994; Le Bras, Pillon, Damier, & Dubois, 1999; MacLeod, 1991; May, Kane, & Hasher, 1995; Mecklinger, Weber, Gunter, & Engle, 2003; Milliken, Joordens, Merikle, & Seiffert, 1998; Mirsky et al., 1991; Neumann & Deschepper, 1992; Reyna, 1995; Roediger, Neely, & Blaxton, 1983; Rothermund & Wentura, 2004; Stadler & Hogan, 1996; Wentura, 1999). Second, schema theory has indicated that a key characteristic of attentional processing is the simultaneous activation of task-relevant schemata in conjunction with the suppression of task-irrelevant schemata (Alba & Hasher, 1983; Armbruster, 1996; Ausubel, 1982; Derry, 1996; Gick & Holyoak, 1983; Klausmeier, 1992; Mandler, 1984; Marshall, 1995; Nuthall, 2000; Schank & Abelson, 1977; Stanovich, 2000).

In addition, prior research in the area of inhibition has also suggested that, in task-related instruction, certain types of language use (information relevance, information cueing, informational valence, and the use of jargon) can act as distracters (Neill, Valdes, & Terry, 1995; cf. Neumann & Deschepper, 1992; Rothermund & Wentura, 2004). These linguistic distractors seem to accord with the types of ambiguous influences identified by students (as discussed in section 5.2.2). The overall logic to hypotheses three to six is, therefore, that the types of instructional encoding used by different teachers will correspond to the amount of cognitive load experienced by the participating students, due to varying demands being made upon inhibition by the encoding differences. Details of how these linguistic distractor types were developed and constructed into specific language elements are presented in section 5.4.3.4.
The final hypothesis for this research predicts that the moderation of mental effort by inhibition will interact with the instructional differences of the teachers, to significantly influence the learning outcomes achieved by the students. This hypothesis is predicated on the notion that via the moderation of cognitive load, inhibition is able to influence the type of achievement outcomes realised by the students. This hypothesis represents a culmination of the logic of the prior hypotheses of the study, in that it seeks to extend the concept of inhibition as a modifier of cognitive load to the point where the load is capable of influencing achievement outcomes. Table 5.2 presents an overview of the study hypotheses, and indicates how each hypothesis was operationalised and measured within the current study.

Table 5.2 Overview of research hypotheses and how each hypothesis is tested

<table>
<thead>
<tr>
<th>Hypothesis</th>
<th>Operational Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1: That a significant, positive relationship exists between WM function and student achievement outcomes.</td>
<td>Students scoring higher on the WM tasks (word recall &amp; maths accuracy, see section 5.4 below) will obtain higher achievement marks than students scoring lower on these tasks. This prediction is in line with prior research and suggests that WM tasks display predictive validity.</td>
</tr>
<tr>
<td>H2: That a significant generalised relationship exists between student inhibitory ability (CI scores) and student cognitive load (CL ratings for the instruction they receive).</td>
<td>Lower CI scores (from the inhibition task, see section 5.4) indicate more efficient inhibitory function, while higher CI scores indicate less efficient inhibition. Lower cognitive load (CL) ratings indicate less mental effort, while higher ratings indicate greater mental effort. Lower CI scores will thus correlate positively to the CL ratings, because the less efficient inhibitory types (higher CI scores) will experience greater mental effort (higher CL ratings), while the more efficient inhibitory types (lower CI scores) will experience less mental effort (lower CL ratings) in relation to their classroom learning.</td>
</tr>
<tr>
<td>H3: That a significant interaction exists between the students’ inhibitory ability (CI), cognitive load ratings (CL), and the way the teachers encode instruction for relevant vs. irrelevant information.</td>
<td>The instructional encoding element RELEVANT represents observational ratings for the way each teacher makes clear distinctions between relevant and irrelevant information. This hypothesis predicts that a statistically significant interaction effect will be found for these ratings in conjunction with scores from the students’ CI &amp; CL measures. This will be measured categorically, using a General Linear Model univariate within-subject analysis of variance.</td>
</tr>
<tr>
<td>H4: That a significant interaction exists between the students’ inhibitory ability (CI), cognitive load ratings (CL), and the way the teachers ask questions in a way that gives irrelevant or distracting semantic cues to the students.</td>
<td>The instructional encoding element CUE represents observational ratings for the way each teacher gives semantically distracting cues when using questioning during lessons. This hypothesis predicts that a statistically significant interaction effect will be found for these ratings in conjunction with scores from the students’ CI &amp; CL measures. This will be...</td>
</tr>
</tbody>
</table>
### 5.4 Data collection

#### 5.4.1 The independent variable of interest to the study

The independent variable of interest for the study was student inhibitory function. Data was collected for this variable by the use of standardised, computer-presented tests administered individually to each student. Feldstein, Keller, Portman, et al. (1999) noted that computerised testing provides “an expanded venue for assessment, which offers certain advantages over the manual method of test administration” (p. 304). Such advantages included a reduced need for extensive training of the test giver, ease of use, a reduction in the potential for bias (such as the Hawthorne effect), reduction in the number of errors commonly made by manual calculation of test scores, an increase in the precision with which the test presents the information content (and records each individual’s response), and the standardisation of test administration. Cassito, Gilioli, and Camerino (1989) pointed out that standardisation is especially helpful when compiling information.
for use in epidemiological studies, where generalisation is an issue. Thus, the use of these computerised tests for the current study was viewed as appropriate to the context and goals of the study.

The initial computerised test used was a measure of WM capacity, the Operation-Word Span Task (OSPAN). This task was used to measure overall WM capacity for the participating students, to ensure they were able to store and process information at a developmentally appropriate level. Information from the OSPAN was also used to assess each student’s specific ability to problem-solve mathematical equations accurately, and to determine how much representational information they could hold in short-term store. The 114 students for whom information was analysed for the study all displayed developmentally appropriate WM capacity. All were able to solve the OSPAN math problems with at least 75% accuracy, and all were able to hold at least 5 items in short-term memory during the WM test.

Inhibition was tested via the administration of a computerised Flanker Task (Ericksen & Ericksen, 1974), as embedded within Posner’s Attentional Networks Test (the ANT). Initially, a Stroop Task was also considered as the inhibition measure, because it is well known as a measure of the degree to which the identity of information can impact on processing (Goldman, 1978; MacLeod, 1991). However, the Flanker provides a test of the impact of both identity and location on processing (Ericksen & Schultz, 1979; Schmidt, & Dark, 1998). The Flanker measures identity and location as processing elements that affect the individual’s ability to perform specific attentional tasks, while being given information cues that are either facilitating to the task, or in conflict with the task. Facilitating cues result in shorter reaction times and higher accuracy for the test item. Conflicting cues result in longer reaction times and less accuracy for the test item. A more detailed discussion of the Flanker Task as used in the study has been provided in section 5.4.3.2a.

5.4.2 The dependent variables of interest to the study

Three types of dependant variable for the study were cognitive load, instructional encoding, and achievement outcomes. These three variables were able to produce a range of individual differences in relation to inhibition: The amount of cognitive load experienced by the students (i.e., correspondences between mental effort and inhibitory

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Lessons formed the basis for a variety of data gathered for the study: Student mental effort ratings, the observational ratings of instructional encoding, and the achievement marks awarded to students. Teachers agreed that the observed lessons were to be presented in the normal course of events and without special preparation. The lessons were chosen by convenient dates, rather than by lesson content.

Cognitive load information was measured by having the students rate (Appendix A) the amount of mental effort required to understand and perform the learning tasks involved in various lessons (Appendix F). Students used a 7-point scale to rate sixteen lessons for each of the participating teachers, spread across one academic year (the criteria for this scale were explained to the students, and they were asked to apply these criteria specifically in relation to how hard they felt they had to work to understand the teacher’s instructions and achieve the learning outcomes for each rated lesson).

Information about instructional ambiguity was also obtained during these sixteen lessons for each participating teacher. Using a 5-point Likert-type scale, a variety of different observers (as detailed in table 5.1) rated four instructional encoding elements for each of the sixteen lessons, according to the observational criteria in Appendix B. These classroom observational ratings are detailed in section 5.4.3.4.

Achievement outcome information was obtained using the assessment marks awarded to the participating students by each of the participating teachers. These marks were awarded to each student on the basis of her or his achievement of the core learning objective for each of the sixteen lessons. Standardised achievement tests were not used in the study due to the complex nature of the research demographics. The use of teacher-awarded achievement marks also better matched the measure of achievement to the
authentic context of the study. These considerations are further discussed in section 5.4.3.5.

5.4.3 Measures

5.4.3.1 WM capacity

WM is generally conceptualised in terms of an individual’s ability to simultaneously store and process information. For this study, WM capacity was measured via the operation-word span task (the OSPAN; Turner & Engle, 1989). The OSPAN is a complex, dual-attention span task that measures the overall processing capacity of WM by invoking a secondary cognitive task (solving mathematical problems) in conjunction with a primary task (short-term store and subsequent recall of words) to measure functional WM capacity. The OSPAN has demonstrated good reliability (using Cronbach’s alpha, reliability estimates for internal consistency average between .89 - .93; see Turner & Engle, 1989, p. 134). A difference for the OSPAN as used in the current study was that, although complex span measures are generally scored in a way that combines both storage and processing components into a single score, the storage component (word recall) and the processing component (accuracy of the arithmetic operations) were analysed separately. In the present study separation allowed specific comparisons between the students’ short-term verbal store and problem-solving accuracy, and the level of cognitive load they experienced, while also allowing for the fact that the difficulty of individual span items can vary on many dimensions (cf. Conway et al., 2005).

The OSPAN was administered to each participating student individually, in a quiet, dedicated testing room set aside in the School’s library. The OSPAN was presented on a laptop PC computer, using SuperLab Pro (v. 2.0). Students were taken into the room, seated before the computer, instructed how to complete the task, and invited to hit any key on the computer keyboard to begin the task. Once started, the students responded to each OSPAN item by hitting one of two (2) buttons on a Cedrus RB-420 response pad, which was set to record response time at the level of a single millisecond. The OSPAN took about 50 minutes to complete.
5.4.3.1a OSPAN scoring

In assigning scores to individual students for the OSPAN, three decisions were made concerning the scoring procedures (cf. Conway et al., 2005):

1. Credit was given to the correct recall of words regardless of whether or not there were errors on the associated mathematical processing component of the task. This decision, to make no distinction between different types of errors on the task, meant that the scoring used did not seek to classify errors in terms of omissions or commissions, or as more-or-less erroneous. This approach allowed for a straightforward scoring method in which particular cognitive processes were not made to compete with one another, as well as one in which the different elements of the task were not conceptually divided.

2. Recall position was also allowed to be flexible. It was decided that the serial position demand exerts an unnecessarily strict scoring procedure, by imposing an “all-or-nothing” accreditation to final scores that confounds the different types of errors involved. In contrast, giving accreditation to correctly recalled words without reference to their original presentation position acknowledges partially correct responses. Overall, this was viewed as affording sufficient precision in the scoring while still allowing for sound psychometric procedures.

3. Weighting parts of the task involving longer attentional focus (i.e., having longer lists of operation-word task items to process) was also not used. Instead, the scoring approach used here gave each task item equal weight as a measure of memory storage in the face of concurrent processing. This approach allowed each item to be scored as a proportion of correctly recalled elements per task-item. The average of all correctly recalled elements was then used to represent the student’s overall task attainment score, irrespective of item length.

5.4.3.2 Cognitive inhibition

WM function involves several mechanisms, including the passive representation of information and an active attentional component (Baddeley, 2001; Bjorkland & Harnishfeger, 1990). It is generally assumed that inhibition supports the attentional component by helping to modify the salience of interfering information (Harnishfeger, 1995). Interference-sensitive tasks have included the Wisconsin Card Sorting Test, the
Stroop task, Rapid Naming Tasks, and the Flanker task. Research has linked interference resolution to inhibitory neurological activity in the anterior cingulate and frontal lobes of the brain (Denkla, 1996; De Young, 2007; Posner & Fan, 2005), and to processes associated with the executive functions of WM (Gerardi-Caulton, 2000; Karatekin, 2004). For such reasons, the current study used a Flanker Task to test student inhibitory function.

5.4.3.2a The Flanker Task

The Flanker Task provided a means of selectively manipulating the presence or absence of response competition while keeping other attentional task demands constant (cf. Hazeltine, Poldrack, & Gabrieli, 2000). In this attentional-priming task, the test-taker is directed at a series of visual items flanked by distracting arrows, letters, or other symbols. Cues to the directed item indicate presentations of distracting symbols in either a congruent or incongruent manner. The goal of the task is to respond to the relevant target stimulus while ignoring irrelevant (flanker) stimuli.

Attentional conflict tasks have been widely used in diagnostic testing (Mayes, Susan & Crowell, 2001). The effect of incongruent, or interfering, response competition (i.e., the flanker effect) has been shown to be highly robust (Miller, 1991), suggesting that attentional processing is quite susceptible to irrelevant or distracting information. The flanker effect has been physiologically measured in studies that map brain function in some way while participants are completing a flanker task. As an example of this, Mattler (2003) found that electrophysiological measures of irrelevant flanker stimuli activate brain activity in both central and peripheral levels of the motor cortex. Peripheral activation in conjunction with central activation suggested that conflicts were being experienced in terms of responding to the stimuli. Green and Bavelier (2003) have shown that such conflict situations result in longer response times (RT), indicating that flanker-based measures of RT provide a valid assessment of conflict processing ability.

Casey et al. (2000) found that the flanker effect was largest on incompatible trials (where the use of irrelevant flankers are more pronounced), and that these trials activated regions in the prefrontal and anterior cingulate systems of the cortex. The anterior cingulate cortex is a prefrontal portion of the brain that is highly sensitive to changes in brain function. The anterior cingulate is generally considered a key neurocognitive
mediator of information deriving from the more impulse-driven parts of the brain in relation to information from the more intentional or strategic brain regions. Thus, the focus of flanker tasks – to maintain selective attention in the face of distracting information – seemed to relate to anterior cingulate function (De Young, 2007; cf. Denkla, 1996; D’Esposito et al., 1998). This view accords with the position of Stanovich (1990), who suggested that interference sensitive tasks actually measure the degree to which conflict situations interrupt the automatic processing of information. For this reason, the use of a flanker task was considered appropriate to the gathering of inhibitory information within a classroom situation.

Flanker information was obtained via the administration of Posner’s Attentional Networks Test (the ANT; cf. Fossella et al., 2002; Posner & Fan, 2008), a complex measure of selective attentional processing that measures a range of attentional processing abilities. Based on Posner’s theory of attention, the ANT measures three distinct attentional functions:

a. Alerting to information,
b. Orienting to the information, and
c. Executive attention.

According to Jin Fan (personal communication, April, 2006), executive attention is concerned with how an individual is able to resolve attentional conflict relating to either the identity or location of information, or both. That is, it indicates how well the person is able to retain attentional focus in light of distracting information. The ANT measures executive attention by comparing accuracy of identification and response time differences for congruent versus incongruent processing conditions, that is, by the use of tasks that elicit responses to a relevant attentional stimulus whilst ignoring irrelevant flanker stimuli. The measure of this function by the ANT, referred to as “conflict data”, was used here as an indicator of individual differences for inhibition among the participating student population. This test thus linked inhibition to priming, in that negative priming is widely viewed as an index of inhibitory control (Gibson, Tipper, & Hewitt, 2005).

An important aspect of the Flanker is its ratio of compatible Flanker stimuli (stimuli that are associated congruently to the target stimulus) to incompatible Flanker stimuli.
stimuli (stimuli that are associated incongruently to the target stimulus). The organisation of this ratio can be manipulated, and serves to modulate the impact of the Flanker effect on any given trail of the task, with larger effects occurring for tasks where the ratio of compatible flankers are about 3/1 to that of incompatible flankers (Casey et al., 2000; cf. Mattler, 2006). In the current study, the ratio of compatible to incompatible flankers for the Flanker Task was 75% to 25% (3/1), indicating that it was a good measure of interference caused by negative priming. Executive attention information as measured by the ANT appears to display significant test-retest coefficients (.87; Fan, Fossella, Sommer, Yanghong, & Posner, 2002), suggesting that the conflict information derived from the ANT is reliable.

Similar to the OSPAN, the ANT was also presented on a laptop PC computer, and was set to record response time at the level of a single millisecond. Students were again taken into the library testing room (on a separate occasion to that of the OSPAN), seated before the computer, instructed how to complete the ANT, and invited to hit any key on the computer keyboard to begin the test. Once started, the students responded to a series of visual presentations by hitting one of the arrow keys on the computer keyboard, and indicating whether a neutral, congruent, or incongruent Flanker task condition had been presented. The ANT took about 40 minutes to complete.

5.4.3.3 Cognitive load

A key focus for the current study was to determine the relationship between inhibition as a causal factor, and several dependent factors, including mental effort, instructional encoding, and achievement outcomes. In this respect, one of the main criticisms of cognitive load theory has been that it currently lacks a necessary and sufficient explanatory mechanism to account for the cognitive load imposed on tasks, and that because of this the theory appears tautological (Gerjets, Scheiter, & Cierniak, 2009; Schnotz & Kürschner, 2007). The current research has sought to add to existing knowledge by investigating whether the amount of cognitive load experienced in relation to learning is affected by the learner’s ability to inhibit information, thereby providing a possible causal mechanism by which the seeming tautology of the theory may be addressed. In accordance with this, the methods used here seek to show that interactions...
between mental load factors and mental effort are influenced via the inhibitory ability of the learner.

Cognitive load was self-reported by the students in relation to lessons they received for each of the participating teachers. The students rated each lesson according to how “hard” they felt they had to work, mentally, to achieve the core learning outcome of the lesson. They did this by assigning a numerical value, on a scale of 1 – 7 (see Appendix A), to the amount of mental effort they experienced during each of the sixteen observed lessons. Individual cognitive load ratings were then averaged for each student, in relation to each of the teachers, in order to deliver an overall average concerning cognitive load as perceived by the student for each teacher. The cognitive load rating criteria were explained to the students initially, and examples of how they were to be applied were given and discussed.

Tipper and Bayliss (1987) also used a self-report measure of cognitive load to determine instructional efficiency. They reported that although cognitive load measures use a self-report format, such measures nevertheless deliver data that is valid and reliable. Cognitive load research has also suggested that such measures are highly reliable, especially when used in conjunction with a dual-task assessment of WM (Ayres, 2006).

Self-report measures of mental effort were used in this study because they allowed a mapping of mental effort differences for the participating students, because they could be compared against individual inhibitory differences for the students, and because they offered a means of categorising instructional differences between the teachers. In addition, the use of self-reported levels of cognitive load by the students allowed the study to test the idea that extraneous cognitive load, which is highly amenable to instructional encoding, was being moderated by inhibition.

Overall, the validity of the self-report measure is adequately established within the literature, and this does not appear to form a significant limitation for the research. However, if future research wishes to approach the issue of cognitive load measure from a different perspective, then it may become time to reconceptualise the validity process for the notion of self-reported cognitive load. Currently, self-report measures of cognitive load
are the accepted norm for this type of research, and thus the thesis seems on solid ground when it comes to this part of the methodology.

5.4.3.4 Instructional encoding

As discussed in section 5.2.2, instructional encoding ratings were developed in relation to four encoding elements of the teachers’ instruction deemed to affect incidental processing and representational holding. These elements were conceptualised as ambiguous processing demands, from the literature review and in conjunction with student interviews. The four elements were:

a) RELEVANT (+): the degree to which the teacher makes clear distinctions between relevant and irrelevant information in relation to the core learning task of the lesson,
b) CUE (-): the degree to which the teacher gives semantically distracting cues when using questioning during lessons,
c) VALENCE (+): the degree to which the teacher defines task-relevant words that possess multiple possible meanings, and
d) JARGON (+): the degree to which the teacher gives clear definitions for jargon words or words that are technically related to a specific area of knowledge.

The processing demands made relative to each of these encoding elements were treated as due to the level of inhibitory function required to process the element during learning. Three of the elements (RELEVANT, VALENCE, & JARGON) exert a positive effect on processing, with higher levels of instructional encoding supportive of more efficient processing. However, the element (CUE) exerted a negative effect on processing, because it refers specifically to the teacher’s use of a distracting prime. Thus, for CUE, higher levels of encoding were seen as detracting from efficient processing. The rating criteria for these four elements are detailed in Appendix B. Table 5.3 details the overall reliability coefficients for each element, as averaged across the sixteen observations for all four teachers.
Table 5.3 Reliability coefficients for observational encoding of instruction

<table>
<thead>
<tr>
<th>Observational Element</th>
<th>Reliability Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>RELEVANCE</td>
<td>0.26</td>
</tr>
<tr>
<td>CUE</td>
<td>0.52</td>
</tr>
<tr>
<td>VALENCE</td>
<td>0.18</td>
</tr>
<tr>
<td>JARGON</td>
<td>0.42</td>
</tr>
</tbody>
</table>

Because these coefficients were found to be less robust than one would wish, especially with respect to the coefficients for RELEVANCE and VALENCE, a more detailed examination of these reliability analyses will be made in chapter 6 (Analyses & Results).

5.4.3.5 Learning achievement outcomes

Achievement outcomes (ACHIEVE) were determined by averaging the sixteen individual achievement marks awarded to the students by each participating teacher, with each achievement mark awarded as a percentage of 100 marks possible. This measure of achievement was utilised, rather than attempting to collect data on standardised achievement test scores, because the teacher assigned marks reflected an in situ classroom measure of learning achievement that was authentically related to the instruction received. As well, the students comprised a mixed ability sample, representing various SES levels and including several different ethnic backgrounds. Since standardised achievement tests can be highly influenced by many such non-school factors, it was felt that the use of standardised data would not provide a measure of achievement that was significantly superior to the teacher assigned marks. Individual achievement scores were used as an indication of the student’s ability to utilise the instructional scaffolding provided by the teacher in relation to their processing abilities.

5.5 Data analysis procedures

This section discusses the methods of analysing the information gathered from the information processing tasks, student self-report measure of cognitive load, observational ratings of the teachers’ instructional encoding, and teacher assigned marks for student achievement.
5.5.1 The General Linear Model

Several different statistical procedures were used to test the relationships between inhibition, mental effort, instructional encoding, and achievement. Fundamental to these analyses was the General Linear Model (GLM) of analysis. The GLM is a general set of statistical procedures commonly used to perform univariate and multivariate analysis of variance and covariance (Tabachnick & Fidell, 2007). In an early description of this approach, Finn (1974) noted that the purpose of the GLM is to signify complex relationships among observable human characteristics using algebraic representations. The GLM encompasses many common statistical analyses, including t-tests, analysis of variance, correlation, and regression. It may be conceptualised as a means of analysing behavioural phenomena in a way that acknowledges the complexity of interactions that can occur, and that assumes that only partial overlap exists between variables that are related to one another (Tabachnick & Fidell, 2007). Appendix C represents the statistical model by which the GLM logic was used to analyse the relationships of interest in the current study. Table 5.4 lists the characteristics of the variables viewed as impacting most directly on the research, as used in these analyses.

Table 5.4 Overview of variables related to the research hypotheses

<table>
<thead>
<tr>
<th>Study Variable</th>
<th>Measurement</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Store (word recall/OSPM)</td>
<td>Mean word recall</td>
<td>4.91</td>
<td>1.29</td>
</tr>
<tr>
<td>Accuracy (math’s operations/OSPM)</td>
<td>% correct (out of 100%)</td>
<td>75.29</td>
<td>11.64</td>
</tr>
<tr>
<td>CI (ANT: Conflict scores)</td>
<td>Response Time (RT) (milscs.)</td>
<td>183.92</td>
<td>75.62</td>
</tr>
<tr>
<td>ACHIEVE (student achievement marks)</td>
<td>% mark (out of 100)</td>
<td>71.37</td>
<td>10.81</td>
</tr>
<tr>
<td>T1_CL (student CL ratings for teacher 1)</td>
<td>7-point scale</td>
<td>4.12</td>
<td>.81</td>
</tr>
<tr>
<td>T2_CL (student CL ratings for teacher 2)</td>
<td>7-point scale</td>
<td>4.23</td>
<td>1.19</td>
</tr>
<tr>
<td>T3_CL (student CL ratings for teacher 3)</td>
<td>7-point scale</td>
<td>4.04</td>
<td>.98</td>
</tr>
<tr>
<td>T4_CL (student CL ratings for teacher 4)</td>
<td>7-point scale</td>
<td>3.48</td>
<td>1.24</td>
</tr>
<tr>
<td>T1_RELEVANT (Encoding observations)</td>
<td>5-point scale</td>
<td>3.64</td>
<td>.51</td>
</tr>
<tr>
<td>T2_RELEVANT (Encoding observations)</td>
<td>5-point scale</td>
<td>2.32</td>
<td>.58</td>
</tr>
<tr>
<td>T3_RELEVANT (Encoding observations)</td>
<td>5-point scale</td>
<td>1.55</td>
<td>.48</td>
</tr>
<tr>
<td>T4_RELEVANT (Encoding observations)</td>
<td>5-point scale</td>
<td>3.50</td>
<td>.46</td>
</tr>
<tr>
<td>T1_CUE (Encoding observations)</td>
<td>5-point scale</td>
<td>3.31</td>
<td>.70</td>
</tr>
<tr>
<td>T2_CUE (Encoding observations)</td>
<td>5-point scale</td>
<td>1.26</td>
<td>.55</td>
</tr>
<tr>
<td>T3_CUE (Encoding observations)</td>
<td>5-point scale</td>
<td>3.34</td>
<td>.68</td>
</tr>
<tr>
<td>T4_CUE (Encoding observations)</td>
<td>5-point scale</td>
<td>2.36</td>
<td>.50</td>
</tr>
<tr>
<td>T1_VALENCE (Encoding observations)</td>
<td>5-point scale</td>
<td>2.18</td>
<td>.45</td>
</tr>
<tr>
<td>T2_VALENCE (Encoding observations)</td>
<td>5-point scale</td>
<td>3.90</td>
<td>.73</td>
</tr>
<tr>
<td>T3_VALENCE (Encoding observations)</td>
<td>5-point scale</td>
<td>2.33</td>
<td>.61</td>
</tr>
<tr>
<td>T4_VALENCE (Encoding observations)</td>
<td>5-point scale</td>
<td>3.33</td>
<td>.77</td>
</tr>
<tr>
<td>T1_JARGON (Encoding observations)</td>
<td>5-point scale</td>
<td>2.04</td>
<td>.47</td>
</tr>
<tr>
<td>T2_JARGON (Encoding observations)</td>
<td>5-point scale</td>
<td>4.68</td>
<td>.91</td>
</tr>
</tbody>
</table>
The variable CI (Conflict scores, representing inhibitory ability) is viewed as the independent variable of interest in the analyses of study data. A brief overview of how each hypothesis is to be analysed is presented below. Full analyses details are discussed in chapter six of the thesis.

5.5.2 H₁: WM X achievement

Prior research strongly suggested that WM function is a reliable indicator of academic achievement. This hypothesis will be tested by analysing correlations that occurred between the students WM functions relating to representational holding (word storage) and their achievement outcomes, as well as by analysing correlations that occurred between their processing accuracy (maths problems correctly solved) and their achievement outcomes.

5.5.3 H₂: Cognitive inhibition X cognitive load

For the question concerning whether or not individual differences in inhibition affect the way students experience mental effort at the classroom level, this hypothesis predicted that a generalised, significant correlation would exist between the students’ inhibition scores and their experience of cognitive load. This hypothesis will be tested by comparing correlations between the students’ inhibition scores (from the Flanker Task) and the average of the cognitive load ratings they assign to the 16 observed lessons. The nature of the predicted relationship is such that students scoring low (CI\textsubscript{Lo}) on the inhibition measure will also rate mental effort lower (CL\textsubscript{Lo}) in relation to the lessons, and that those students scoring higher (CI\textsubscript{Hi}) on the inhibition measure will also rate the mental effort required as higher (CL\textsubscript{Hi}) in relation to the lessons.

5.5.4 H₃: Inhibition X cognitive load X RELEVANCE

This hypothesis will be analysed by using a within-subjects analysis of variance (ANOVA), involving the students’ inhibition scores, X their cognitive load ratings, X the degree to which each teacher made clear distinctions between relevant and irrelevant information during the observed lessons.
5.5.5 \( H_5 \): Inhibition X cognitive load X CUE

This hypothesis will be analysed by using a within-subjects analysis of variance (ANOVA), involving the students’ inhibition scores, X their cognitive load ratings, X the observational ratings made for the way each teacher cued for irrelevant processing while questioning the students during the observed lessons.

5.5.6 \( H_6 \): Inhibition X cognitive load X VALENCE

This hypothesis will be analysed by using a within-subjects analysis of variance (ANOVA), involving the students’ inhibition scores, X their cognitive load ratings, X the observational ratings made for the way each teacher used words that had multiple possible meanings during the observed lessons (without clarifying the precise relevant meaning).

5.5.7 \( H_7 \): Inhibition X cognitive load X JARGON

This hypothesis will be analysed by using a within-subjects analysis of variance (ANOVA), involving the students’ inhibition scores, X their cognitive load ratings, X the observational ratings made for the way each teacher clarified the meanings of technical or jargon words during the observed lessons.

5.5.8 \( H_8 \): Inhibition X cognitive load X achievement outcomes

This hypothesis relates to the question of whether inhibition and mental effort affect the types of learning outcomes the students achieved with the different teachers. To test this hypothesis, a within-subjects analysis of variance (ANOVA) examined the students’ inhibition scores, X their cognitive load ratings, X the achievement scores awarded by each teacher.

5.6 Limitations and unexpected difficulties

It is acknowledged that, in every educational setting, each group of students present a unique collection of factors, including personality traits, abilities and skills, learning experience, and educational background. A common limitation for any
methodology, therefore, is the inability to completely control the influence of all such possible variables upon the research findings (Grimm & Yarnold, 2000). Nonetheless, analyses of the variables of interest form an appropriate concern for the study, in light of the information they provide with respect to the stipulated research questions and hypotheses.

5.7 Ethical considerations

After obtaining ethics approval for the research (University ethics committee approval ECN-03-157, Department of Education and Training approval SERAP 04.44), a prospective power analysis was conducted (Tabachnick & Fidell, 2007). Using an alpha level of 0.05, and assuming one independent factor (inhibitory function), with three dependent factors (cognitive load, instructional encoding, and achievement outcomes), the power analysis indicated that the sample size would detect a moderate effect, controlling for type II errors with a statistical power of 0.56. In accordance with the National Statement on Ethical Conduct in Human Research (Australian Government, 2007), the study methods posed little potential for harm, discomfort, or inconvenience to participating students and teachers. As well, the theoretical value of the study was considered important, as it may have significant implications for both instructional design and cognitive load theory. Therefore, teacher, student, and parental permission for the study to proceed were organised, and the study was implemented. The results and analyses of the study findings are presented in chapter six of the thesis.
CHAPTER 6: ANALYSIS AND RESULTS

Instruction does not lead to learning automatically. The learning activities that students employ determine to a large extent the quality of the learning outcomes they achieve.


6.0 Introduction

This chapter will describe the recoding and categorising procedures used to analyse the data from the investigation of inhibition and cognitive load. These procedures are utilised in order to organise the analyses into coherent and meaningful interpretive groups. The results of these analyses will then be presented in collated format. Some initial conclusions are presented in this chapter as well, where required by the data and by the results obtained.

6.1 Preliminary analyses

This study examined the relationship between student inhibitory ability and the amount of cognitive load experienced during learning in relation to:

a) The generalised relationship between inhibition and mental effort;

b) Inhibition and mental effort in relation to instructional encoding; and

c) Inhibition and mental effort in relation to achievement outcomes.

In order to examine these relationships more clearly, some recoding of variable information was required prior to the analyses, in order to account for variables that had been rated in a reverse manner (CUE), or that needed to be dichotomised according to categorical distinctions (student inhibition data [CI_Groups]; and student cognitive load data [CL_Ov_Grp]). Dichotomisation of the inhibition and cognitive load data was performed because it allowed this information to be analysed from the relative perspective of grouped divisions. Grouping was considered desirable as it afforded an additional level of comparison when analysing this independent variable information in relation to the other study variables.

Dichotomisation for inhibition and cognitive load was carried out by first determining the distribution characteristics for each variable (range, minimum–maximum scores, mean,
median, mode, and standard deviation). Then, the distribution was inspected for either skewness or kurtosis, due to the presence of outliers. Characteristics of the inhibition and cognitive load data are presented in Table 6.1. It can be seen that the inhibition scores displayed a mild skewness (.74), due to the presence of several outliers (scores >321) in this distribution, and that the cognitive load scores displayed a very slight, negative skewness (-.09). Tabachnick and Fidell (2007) have stated that the median score, because it depends on rank ordering, is less affected by skewness and, therefore, provides a more appropriate measure of central tendency for such distributions. In addition, for both inhibition and cognitive load as measured for the current study, the median score marks the 50th percentile point of the distribution. On this basis, dichotomous grouping for the inhibition scores (CI_Groups) was determined by using the median score (161.00) of the inhibition distribution, to distinguish between the more-able inhibitors (0 – 160.99) and the less-able inhibitors (≥ 161.00). Likewise, grouping for the cognitive load scores (CL_Ov_Grp) used the median of the cognitive load scores (3.88), to distinguish between those students experiencing less-mental effort (0 – 3.88) and those experiencing more-mental effort (≥ 3.89). Note, however, that the data for inhibition and cognitive load were also retained in their original, dimensional format as well as recoded into a categorical format. This dual coding approach was performed to allow the influence of these variables to be analysed in both dimensional and categorical terms.

Table 6.1 Characteristics of grouped variable distributions

<table>
<thead>
<tr>
<th>Variable</th>
<th>Range</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>Med</th>
<th>Mode</th>
<th>SD</th>
<th>Skewness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inhibition (CI)</td>
<td>382</td>
<td>79</td>
<td>461</td>
<td>170.44</td>
<td>161.00</td>
<td>97.00</td>
<td>54.28</td>
<td>.741</td>
</tr>
<tr>
<td>Cog. Load (CL)</td>
<td>3.25</td>
<td>2.00</td>
<td>5.25</td>
<td>3.91</td>
<td>3.88</td>
<td>4.00</td>
<td>.64</td>
<td>-.09</td>
</tr>
</tbody>
</table>

Inhibition scores (labelled CI in these analyses) were not reverse-coded for these analyses. This in spite of the fact that the original measure of these scores represented a negative numerical direction (i.e., lower scores represent higher inhibitory ability, and higher scores represent lower inhibitory ability). This decision was made because of the second hypothesis, which predicted that the inhibition scores would maintain a positive relationship with the cognitive load scores. This prediction was made on the basis that the cognitive load scores (labelled CL in these analyses) are contraindicated in relation to inhibition (with lower CL scores indicating less mental effort, and higher CL scores
indicating greater mental effort). Thus, the second hypothesis predicted that lower mental effort scores (CL) would coincide with higher inhibition scores (CI), and that higher mental effort scores would coincide with lower inhibitory ability. The second study hypothesis then predicted an overall positive relationship between these two measures, on the expectation that students with greater inhibitory ability (measuring lower on the CI scores) would also experience less mental effort (measuring lower on the CL scores), and that students with less inhibitory ability (measuring higher on the CI scores) would also experience greater mental effort (measuring higher on the CL scores).

6.1.1 Participant characteristics

A descriptive overview of characteristics for the main variables relating to student participants is represented in Table 6.2. The student sample was fairly evenly distributed between the sexes (females 51%, males 49%), and the average age for the participants was 13.8 years ($SD = .39$).

<table>
<thead>
<tr>
<th>Table 6.2 Overview of student participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
</tr>
<tr>
<td>----</td>
</tr>
<tr>
<td>Age</td>
</tr>
<tr>
<td>Inhibition (CI) Scores</td>
</tr>
<tr>
<td>Cognitive Load (CL) Scores</td>
</tr>
<tr>
<td>Achievement Marks</td>
</tr>
</tbody>
</table>

Inspection of the relationships between these characteristics did not appear to reveal any effect for age and gender, either in terms of overall achievement scores (Ov_Ach, see Figure 6.1) or in terms of cognitive load (CL, see Figure 6.2).
Figure 6.1 Overall achievement scores in relation to age and gender.

Figure 6.2 Cognitive load in relation to age and gender.
The distribution of inhibitory ability among the study participants (CI_Grps, see Figure 6.3) did appear to reveal some differences. The older boys were more widely represented across both the high and low inhibitory ability groups, while the older girls tended to be more clustered within the low ability group. For both girls and boys, the general trend was for younger students to exhibit more effective inhibitory ability, although note that none of these relationships were significant.

![Inhibition by Age & Gender](image)

*Figure 6.3 Inhibition in relation to age and gender.*

Overall, these differences involved a fairly small range. A univariate test of between subjects effects for these variables indicated that the relationship between inhibition, age, and gender is not statistically significant, $F(2,14) = 0.76$, $p < .71$, $\eta^2 = .01$. As shown in Figure 6.4, the primary source of difference in this relationship stems from gender-based age differences. A large number of female students were close to the mean age of the participant sample (13.92 yrs.), and the male cohort contained a higher number of older participants (>14.25 yrs.).
Figure 6.4 Overview of gender in relation to age for student participants.

Because age and gender did not influence the sample characteristics relating to achievement, mental effort, or inhibitory ability, no further analyses relating specifically to statistical significance for age and gender were performed for the study.

6.1.2 Special note on the reliability analyses for instructional encoding

As noted in chapter 4, reliability coefficients (Cronbach’s Alpha) for the observations of instructional encoding were quite varied. The instructional elements RELEVANT and VALENCE returned low coefficients, while those for CUE and JARGON were moderate. Hence, these coefficient outcomes were examined more closely, in order to better understand the meaning of these findings within the context of the current study. The details of these coefficient analyses are provided as Appendix E. The overall results and interpretations of these analyses are summarised here.
6.1.2.1 Overall results and interpretations of reliability coefficients for the instructional encoding elements

Taken together, the correlation and covariance data for these elements show that RELEVANCE and VALENCE received less observational reliability within the study, while both CUE and JARGON received greater observational reliability. Summarising the data from Appendix E, there appear to be similarities between teachers T2, T3, and T4 for RELEVANCE, VALENCE, and JARGON. There also appears to be substantial similarity in the encoding for CUE between teachers T3 and T4, with some similarity also occurring for T4 in relation to T1 and T2. The point of difference across all these observations appears to be teacher T1, who is consistently viewed as encoding in a manner opposed to the other teachers. Thus, T1 seems to bring a distinct instructional influence within the study, and it appears that at least some of the inter-rater reliability differences stem from the effects of this influence.

Table 6.3 provides a comparative overview of how each of the four instructional elements was encoded by these teachers. Note that T1 encoded lowest for two of the four elements (RELEVANCE and VALENCE), and encoded the second lowest for JARGON. This comparison further suggests that the instructional encoding for T1 was observed as being distinct from the encoding of the other teachers. It is the interpretation of these analyses that T1 had substantial bearing upon the results of the overall reliability analyses, causing them to be lower in general than they otherwise would have been.

Table 6.3 Overview of instructional encoding results

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Relevance</th>
<th>Cue</th>
<th>Valence</th>
<th>Jargon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall Enc</td>
<td>2.72</td>
<td>2.45</td>
<td>2.93</td>
<td>2.77</td>
</tr>
<tr>
<td>T1 Avg.</td>
<td>2.14</td>
<td>3.34</td>
<td>2.28</td>
<td>2.12</td>
</tr>
<tr>
<td>T2 Avg.</td>
<td>3.39</td>
<td>1.33</td>
<td>3.81</td>
<td>3.83</td>
</tr>
<tr>
<td>T3 Avg.</td>
<td>2.18</td>
<td>2.84</td>
<td>2.32</td>
<td>1.93</td>
</tr>
<tr>
<td>T4 Avg.</td>
<td>3.16</td>
<td>2.31</td>
<td>3.30</td>
<td>3.20</td>
</tr>
<tr>
<td>Lowest Avg.</td>
<td>T1</td>
<td>T2</td>
<td>T1</td>
<td>T3</td>
</tr>
</tbody>
</table>

Overall, the data as analysed in Appendix B suggest that a fair amount of dissimilar instructional encoding exists for the group of participating teachers. Indeed, individual differences recorded for student inhibitory ability seem to be matched here by individual differences in instructional encoding. With this in mind, preliminary analyses of the other
study variables were undertaken, to determine whether those variable relationships appeared valid and worthy of inferential analysis.

6.1.3 Variable characteristics and relationships

The variable CI (representing inhibition) is viewed as the independent variable of interest in these analyses. This variable, along with the cognitive load ratings assigned to the four teachers (t1 – t4_cg ld), outcomes for the specified WM tasks (RECALL and ACCURACY), and the student achievement marks (ACHIEVE), were all normally distributed. A reliability analysis (Cronbach’s Alpha) for the cognitive load ratings returned .45. Using the teacher-awarded achievement scores (derived from the sixteen lesson tasks assessed by each teacher), the overall Cronbach’s Alpha for ACHIEVE was .83. Reliability estimates for RECALL x ACCURACY x ACHIEVE were .58. Of interest, the students also assigned cognitive load ratings to the OSPAN and ANT tasks, and these two ratings were significantly correlated, \( r(114) = .37, p < .01 \). This is not surprising in that both these tasks measure inter-related aspects of attentional processing, which is dependent upon executive WM function.

As expected, the inhibition measure (CI) was significant and negative in relation to the other WM measures. The correlation between ACCURACY and CI was \( r(114) = -.26, p < .05 \), and the correlation between RECALL and CI was \( r(114) = -.23, p < .05 \). These findings suggest that the ability to process problem-solving information (ACCURACY), and to hold representational information (RECALL) in short-term store while suppressing ongoing information, is affected by the amount of inhibitory processing required. A Wilk’s Lambda for the relationship between student inhibition and the cognitive load ratings the students assigned to the ANT was also significant, \( F(50,58) = 1.61, p < .05 \), indicating that the ANT taps into inhibition as part of the mental effort required to complete the task.

Due to these results, and because normality assumptions appear to have been met for the data, further analyses were performed to test the specific study hypotheses, using a nominal alpha of .05. Note that some effects were observed in each of the areas of interest (generalised mental effort, mental effort in relation to instructional encoding, and mental effort in relation to achievement outcomes). These findings indicate that the learner’s level of cognitive load was being influenced by either the individual’s ability to inhibit task-
irrelevant information or by the task-driven need to inhibit task-irrelevant information, both important aspects of cognitive load theory.

6.2 Results relating to the first hypothesis

The first hypothesis predicted a significant, positive relationship between WM function and student achievement outcomes. This hypothesis is in keeping with a large body of evidence suggesting that WM function is highly correlated with learning (cf. Conway et al., 2005). It is tested here in order to establish that the sample for the current study demonstrated developmentally appropriate levels of WM function, as well as indicating that these students were responding to the WM measure in a manner similar to that established by prior research.

The WM functions of interest were defined in terms of student scores on the OSPAN relating to representational holding (word recall) and active processing (accuracy in solving math problems), both measures relating to classroom learning. Correlations between student achievement outcomes and the WM measures were highly significant, with RECALL and ACHIEVE returning $r(114) = .26, p < .01$, two tails, and ACCURACY and ACHIEVE returning $r(114) = .24, p < .02$, two tails. A univariate test of between-subjects effects for the relationship between RECALL and ACHIEVE returned $F(108,5) = 5.41, p < .04, \eta^2 = .062$. Between-subjects effects for ACCURACY and ACHIEVE returned $F(108,5) = 4.56, p < .06, \eta^2 = .058$. Although the results for ACCURACY and ACHIEVE only suggests a trend, when taken together, these findings support the first hypothesis.

6.3 Results relating to the second hypothesis

In terms of generalised mental effort, Hypothesis two had predicted a significant relationship between student inhibitory function (as measured by conflict scores from the embedded Flanker Task) and the cognitive load ratings the students assigned to their learning. In this relationship, the more able inhibitors were expected to assign less cognitive load to their learning, while the less able inhibitors were expected to assign more cognitive load to their learning. Although the expectation was that a positive relationship would occur between these variables, two-tailed tests of significance were also used to test
As an initial test of this hypothesis, using Pearson’s correlation, the cognitive load ratings awarded to each teacher by the students were correlated with the students’ inhibition scores using four different approaches. The teacher analyses were conducted to see the extent to which the individual student differences for cognitive load might vary in relation to instructional encoding differences (i.e., extrinsic cognitive load, or “imposed inhibition”) between the teachers.

1. The overall dimensional (continuous) inhibition scores (CI) were correlated against the dimensional (continuous) cognitive load ratings for each teacher (t1 – t4_cg.ld), to determine whether these scores indicated a generalised relationship that was independent of any groupings that might be made for the data.

2. The overall inhibition scores were grouped categorically (CI_Grps, based on the mean inhibition score), and correlated against the dimensional cognitive load ratings for each teacher (t1 – t4_cg.ld). This analysis was performed to determine whether a categorical distinction between the more able and less able inhibitors would also influence the relationship between inhibition and cognitive load.

3. The overall dimensional inhibition scores (CI) were correlated against cognitive load ratings that had been categorically grouped for each teacher (T1 – T4_CL, based on the mean cognitive load score), as an initial look at how the higher versus lower mental effort groupings might influence the relationship.

4. The overall categorical inhibition scores (CI_Grps) were correlated against categorical cognitive load ratings (T1 – T4_CL), to determine whether the grouped differences influenced this relationship in a distinctive manner.

1) First, correlations between the overall dimensional inhibition scores (CI) in relation to individual teachers’ dimensional cognitive load ratings (t1 – t4_cg.ld) were significant for three of the four teachers, as shown in Table 6.4.
Table 6.4 Correlations between overall dimensional inhibition and dimensional cognitive load for each teacher

<table>
<thead>
<tr>
<th></th>
<th>t1_cg.ld</th>
<th>t2_cg.ld</th>
<th>t3_cg.ld</th>
<th>t4_cg.ld</th>
</tr>
</thead>
<tbody>
<tr>
<td>CI</td>
<td>.228(*)</td>
<td>.198(*)</td>
<td>.186(*)</td>
<td>.136</td>
</tr>
</tbody>
</table>

n = 114

(*) p < .05, 2-tails

2) Second, correlations between the categorically grouped inhibition scores (CI_Grps) in relation to the dimensional cognitive load ratings for the teachers (t1 – t4_cg.ld) were significant for two of the teachers, as shown in Table 6.5. Note however, that this grouping method has picked up the possible influence of T1 more strongly than did the first analysis of these variables.

Table 6.5 Correlations between CI_Grps and the dimensional cognitive load scores for each teacher

<table>
<thead>
<tr>
<th></th>
<th>t1_cg.ld</th>
<th>t2_cg.ld</th>
<th>t3_cg.ld</th>
<th>t4_cg.ld</th>
</tr>
</thead>
<tbody>
<tr>
<td>CI_Grps</td>
<td>.339(**)</td>
<td>.184(*)</td>
<td>.167</td>
<td>.153</td>
</tr>
</tbody>
</table>

n = 114

(**) p < .01, 2-tails

(*) p < .05, 2-tails

3) Third, correlations between the overall dimensional inhibition scores (CI) in relation to the cognitive load ratings that had been categorically grouped (T1 – T4_CL) were significant for all four teachers, being highly significant for three of them, as shown in Table 6.6.

Table 6.6 Correlations between overall dimensional inhibition and grouped cognitive load ratings for each teacher

<table>
<thead>
<tr>
<th></th>
<th>T1_CL</th>
<th>T2_CL</th>
<th>T3_CL</th>
<th>T4_CL</th>
</tr>
</thead>
<tbody>
<tr>
<td>CI</td>
<td>.307(**)</td>
<td>.212(*)</td>
<td>.325(**)</td>
<td>.243(**)</td>
</tr>
</tbody>
</table>

n = 114

(**) p < .01, 2-tails

(*) p < .05, 2-tails
4) Finally, correlations between the grouped (CI_Grps) inhibition scores and the grouped (T1 – T4_CL) cognitive load ratings were significant for three of the four teachers, and again highly significant for two of them. It is worth noting that T1, the teacher who was observed as encoding quite differently to the other teachers for most of the instructional elements, has the highest correlation. As shown in Table 6.7, it appears that the instructional encoding for this teacher produced the most noticeable mental effort results in relation to the more-versus-less-able inhibitor grouping, with the greatest amount of mental effort being experienced in relation to this teacher.

Table 6.7 Correlations between CI_Grps and grouped cognitive load ratings for each teacher

<table>
<thead>
<tr>
<th>CI_Grps</th>
<th>T1_CL</th>
<th>T2_CL</th>
<th>T3_CL</th>
<th>T4_CL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>.440(**)</td>
<td>.194(*)</td>
<td>.341(**)</td>
<td>.142</td>
</tr>
</tbody>
</table>

n = 114

(**) p < .01, 2-tails

(*) p < .05, 2-tails

6.3.1 Overview of results relating to the second hypothesis

Although the concordance between these various findings may be considered somewhat mixed in relation to supporting the second hypothesis, there is notable and consistent support for the relationship between inhibition and mental effort for T1 and T3, moderate and substantial support for T2, and some support for T4. That is, the overall direction of this relationship is positive, as predicted by the assumption that more able inhibitors (scoring lower on the Conflict measure) would also experience less mental effort in their learning (recording lower cognitive load scores), while the less able inhibitors (scoring higher on the Conflict measure) would experience greater mental effort (recording higher cognitive load scores). The predicted direction of this relationship is clearly supported by these findings.

Figure 6.5 displays the overall relationship between mental effort (CL) and grouped inhibitory ability (CI_Grps) for students in relation to each of the four teachers. This figure is included to provide a visual aide for understanding how the more-able and less-able inhibitors reacted to differences between the teachers. Looking at this visual representation, it is clear that T1 elicited the greatest amount of mental effort overall. T1 also produced the
sharpest categorical mental effort differences between the more able versus less able inhibition groups. T2 elicited the lowest amount of mental effort overall, and, of particular note, was the only teacher who seemed to scaffold for lower mental effort amongst the less-able inhibitors. This may make more sense when viewed in relation to the previously detailed instructional encoding results, where it was observed that T2 encoded the highest of all the teachers for three out of the four instructional elements: RELEVANCE, VALENCE, and JARGON.

*Figure 6.5 Teacher-specific cognitive load in relation to inhibitory group.*

Because these findings were teacher-specific, correlations were also analysed for overall inhibition in relation to overall mental effort. For these analyses, student cognitive load scores for the four teachers were summed and averaged, to derive an overall mental effort distribution, which was dimensional (continuous) in form (CL_Ov_Dm). This distribution ranged from 2 to 5.25, with a mean of 3.90 (Median = 3.88, mode = 4.00, SD = .64). This distribution was then compared against the dimensional inhibition (CI) scores. The correlation between these variables was $r_{(114)} = .31, p < .01$. 
Using the median score, the overall (dimensional) mental effort distribution was then transformed to create a categorically grouped variable (CL_Ov_Grp), and compared against the grouped inhibitory variable (CI_Grps). The purpose of this comparison was to determine whether the categorical distinctions, which had proven stronger for the individual teachers, would also reveal a stronger emphasis for the overall relationship between inhibitory function and mental effort. The correlation for this analysis was $r(114) = .35, p < .01$. Given the significance of these correlational findings, a univariate analysis of between-subjects effects was also performed, to determine the impact of inhibition on mental effort for these students. With inhibition as a fixed factor, and mental effort as the dependent variable, the between-subjects effects analysis returned $F(77,36) = 1.692, p < .04, \eta^2 = .32$.

Overall, these findings appear to support the second hypothesis. Although the individual teacher comparisons were somewhat mixed, the majority of these analyses indicate that a significant relationship exists between student inhibitory function and the cognitive load ratings the students assigned to their learning. Furthermore, the predicted nature of the hypothesised relationship was supported, and analyses of inhibition and mental effort as generalised variables received strong support in both dimensional and categorical terms. Finally, the between-subjects analysis, using inhibition as the IV and mental effort at the DV, suggests that inhibition accounted for a significant amount of the mental effort experienced in relation to learning.

### 6.4 Results relating to the third hypothesis

Whereas the second hypothesis had predicted that a generalised relationship existed between the inhibitory ability of students and the amount of mental effort they experienced in relation to learning, the third hypothesis focused this relationship upon the single instructional encoding element of RELEVANCE. This hypothesis predicted a significant interaction effect between student inhibitory function, the amount of mental effort experienced by the student, and the way RELEVANCE was encoded as an instructional element by the teacher.
To test the relationship between inhibition, mental effort, and the encoding of RELEVANCE, a series of mixed design (CI_Grps x T1 – T4_CL x T1 – T4_rel) Analysis of Variance (ANOVA) tests was performed. Homogeneity assumptions were met, with both Box’s M and Levene’s tests being nonsignificant. Table 6.8 provides an overview of the findings from these ANOVAs.

Table 6.8 Overview of ANOVA findings for RELEVANCE interaction (CI_Grps x T1 – T4_CL x T1 – T4_rel.)

<table>
<thead>
<tr>
<th>Teacher</th>
<th>ANOVA Finding</th>
<th>Hypothesis Supported?</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>$F(2,14) = 5.58, p &lt; .06, \eta^2 = .14$</td>
<td>Possible Trend</td>
</tr>
<tr>
<td>T2</td>
<td>$F(2,14) = 2.21, p &lt; .16, \eta^2 = .06$</td>
<td>No</td>
</tr>
<tr>
<td>T3</td>
<td>$F(2,14) = .50, p &lt; .26, \eta^2 = .12$</td>
<td>No</td>
</tr>
<tr>
<td>T4</td>
<td>$F(2,14) = 9.20, p &lt; .04, \eta^2 = .13$</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Results were teacher specific. A significant, first order interaction between inhibitory group, mental effort, and the encoding of RELEVANCE was found for teacher T4, indicating that the way this teacher discriminated between relevant and irrelevant information during instructional delivery elicited greater mental effort from students. No significant interactions were found for teachers T2 and T3. A possible trend may be occurring for T1, suggesting that this teacher may also be discriminating relevant from irrelevant information during instruction in a manner causing students to experience more mental effort. In addition to these interactions, between subjects effects were found for inhibition in relation to RELEVANCE for T2 ($F_{1,15} = 17.09, p < .03, \eta^2 = .29$), and for T4 ($F_{1,15} = 4.90, p < .05, \eta^2 = .24$).

6.5 Results relating to the fourth hypothesis

The fourth hypothesis predicted a significant interaction effect between student inhibitory function, the amount of mental effort experienced by the student, and the way CUE was encoded as an instructional element. Again, a series of mixed design (CI_Grps x T1 – T4_CL x T1 – T4_cue) Analysis of Variance (ANOVA) tests was performed to test
this hypothesis. Homogeneity assumptions were met, with both Box’s M and Levene’s tests being nonsignificant. Table 6.9 provides an overview of these ANOVAs.

Table 6.9 Overview of ANOVA findings for CUE interactions (CI_Grps x T1 – T4_CL x T1 – T4_cu).

<table>
<thead>
<tr>
<th>Teacher</th>
<th>ANOVA Finding</th>
<th>Hypothesis Supported?</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>$F(2,14) = 8.20, p &lt; .07, \eta^2 = .16$</td>
<td>Possible Trend or Direction</td>
</tr>
<tr>
<td>T2</td>
<td>$F(2,14) = 2.10, p &lt; .20, \eta^2 = .08$</td>
<td>No</td>
</tr>
<tr>
<td>T3</td>
<td>$F(2,14) = 1.43, p &lt; .41, \eta^2 = .03$</td>
<td>No</td>
</tr>
<tr>
<td>T4</td>
<td>$F(2,14) = 1.20, p &lt; .35, \eta^2 = .05$</td>
<td>No</td>
</tr>
</tbody>
</table>

For three of the four teachers (i.e., T2 – T4), there were no significant, first order interactions between inhibitory group, mental effort, and the encoding of CUE. A possible trend or direction may be occurring for T1, suggesting this teacher may be providing more semantically distracting information than the other teachers when questioning the students. No between subjects effects were found for any of these variables.

6.6 Results relating to the fifth hypothesis

The fifth hypothesis predicted a significant interaction effect between student inhibitory function, the amount of mental effort experienced by the student, and the way VALENCE was encoded as an instructional element. As with the other instructional encoding elements, a series of mixed design (CI_Grps x T1 – T4_CL x T1 – T4_val) Analysis of Variance (ANOVA) tests was performed to test this hypothesis. Homogeneity assumptions were met, with both Box’s M and Levene’s tests being non-significant. Table 6.10 provides an overview of these ANOVAs.

Table 6.10 Overview of ANOVA findings for VALENCE (CI_Grps x T1 – T4_CL x T1 – T4_val.)

<table>
<thead>
<tr>
<th>Teacher</th>
<th>ANOVA Finding</th>
<th>Hypothesis Supported?</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>$F(2,14) = .53, p &lt; .51, \eta^2 = .11$</td>
<td>No</td>
</tr>
<tr>
<td>T2</td>
<td>$F(2,14) = .13, p &lt; .75, \eta^2 = .06$</td>
<td>No</td>
</tr>
<tr>
<td>T3</td>
<td>$F(2,14) = .77, p &lt; .62, \eta^2 = .08$</td>
<td>No</td>
</tr>
<tr>
<td>T4</td>
<td>$F(2,14) = .74, p &lt; .59, \eta^2 = .09$</td>
<td>No</td>
</tr>
</tbody>
</table>
No significant, first order interactions between inhibitory group, mental effort, and the encoding of VALENCE were found for any of the teachers. In addition, no between subjects effects were found for any of the variables.

6.7 Results relating to the sixth hypothesis

The sixth hypothesis predicted a significant interaction effect between student inhibitory function, the amount of mental effort experienced by the student, and the way JARGON was encoded as an instructional element. As with the other instructional encoding elements, a series of mixed design (CI_Grps x T1 – T4_CL x T1 – T4_jar) Analysis of Variance (ANOVA) tests was performed to test this hypothesis. Homogeneity assumptions were met, with both Box’s M and Levenes’s tests being non-significant. Table 6.11 provides an overview of these ANOVAs.

<table>
<thead>
<tr>
<th>Teacher</th>
<th>ANOVA Finding</th>
<th>Hypothesis Supported?</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>$F_{(2,14)} = 2.69, p &lt; .10, \eta^2 = .21$</td>
<td>Possible Direction</td>
</tr>
<tr>
<td>T2</td>
<td>$F_{(2,14)} = .95, p &lt; .57, \eta^2 = .02$</td>
<td>No</td>
</tr>
<tr>
<td>T3</td>
<td>$F_{(2,14)} = 2.20, p &lt; .19, \eta^2 = .11$</td>
<td>No</td>
</tr>
<tr>
<td>T4</td>
<td>$F_{(2,14)} = 1.25, p &lt; .53, \eta^2 = .07$</td>
<td>No</td>
</tr>
</tbody>
</table>

As shown in Table 6.11, none of the teachers showed significant interactions between inhibition, mental effort, and the instructional encoding of JARGON. For T4, it appeared that a between subjects direction may be occurring for inhibition in relation to JARGON ($F_{[1,15]} = 9.38, p < .06, \eta^2 = .29$), but post hoc tests revealed no significant sub effects for this relationship.

6.8 Summary of findings relating to the instructional encoding hypotheses (H3–6)

Summarising the analyses of the instructional encoding elements (Hypotheses 3–6), it appears that very little support can be found for the notion that a significant interaction effect exists between student inhibitory function, the amount of mental effort they experience, and the way the nominated instructional elements were encoded by the teachers, as these elements were interpreted and operationalised for the study. Only two
teachers (T1 and T4) showed directional tendencies in these analyses, and only the encoding of RELEVANCE by T4 received clearly significant support. The low level of inter-rater agreement from the observations of the instructional elements, or the way that the elements were conceptualised as a measure of the students’ information processing abilities may have contributed to these outcomes. In either case these findings are disappointing, particularly given the support gained for hypotheses one and two. Nevertheless the support found for T4 in relation to RELEVANCE, as well as some suggestion that a trend or direction may have been occurring in places, suggests that the underlying notion (that the way teachers organise and encode instructional information does interact with the learner’s inhibitory ability and experience of mental effort) should continue to be considered, and tested again, albeit using a different operational approach.

6.9 Results relating to the seventh hypothesis

The seventh hypothesis predicted a significant interaction between student inhibitory function, the amount of mental effort experienced during learning, and the achievement outcomes produced by the students. This prediction is important because it indicates whether or not the hypothesised moderation of mental effort by inhibition was able to influence student achievement within the current research context. This hypothesis was tested at two levels: by testing these relationships (a) for each individual teacher and (b) overall for the four teachers.

For testing at the individual teacher level, a series of univariate tests of between-subjects effects were performed for inhibition X individual teacher cognitive load X individual teacher achievement marks. These tests were performed using both the grouped inhibition variable (CI_Grps x T1 – T4_CL x T1 – T4_Achieve) and the dimensional inhibition variable (CI x T1 – T4_CL x T1 – T4_Achieve). Homogeneity assumptions were met for all these variables, with both Box’s M and Levene’s tests being nonsignificant. Table 6.12 provides an overview of the ANOVAs relating to the grouped inhibition tests.

Table 6.12 Overview of ANOVA findings for achievement in relation to grouped inhibition, by individual teacher (CI_Grps x T1 – T4_CL x T1 – T4_Achieve)
The second series of univariate between-subjects effects for the individual teachers used the dimensional inhibition variable X individual teacher cognitive load X individual teacher achievement marks (CI x T1 – T4_CL x T1 – T4_Achieve) to test this same hypothesis. Table 6.13 provides an overview of the ANOVAs relating to these dimensional inhibition tests.

Table 6.13 Overview of ANOVA findings for achievement in relation to dimensional inhibition, by individual teacher (CI x T1 – T4_CL x T1 – T4_Achieve)

<table>
<thead>
<tr>
<th>Teacher</th>
<th>ANOVA Finding</th>
<th>Hypothesis Supported?</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>( F(87,1,15) = 4.31, p = .056, \eta^2 = .23 )</td>
<td>Directional</td>
</tr>
<tr>
<td>T2</td>
<td>( F(92,6,14) = 2.47, p = .14, \eta^2 = .05 )</td>
<td>No</td>
</tr>
<tr>
<td>T3</td>
<td>( F(89,8,3) = 5.72, p = .03, \eta^2 = .28 )</td>
<td>Yes</td>
</tr>
<tr>
<td>T4</td>
<td>( F(90,11,11) = 1.77, p = .21, \eta^2 = .04 )</td>
<td>No</td>
</tr>
</tbody>
</table>

For testing at the overall sample level, a series of univariate tests of between-subjects effects were performed for inhibition X overall cognitive load X overall achievement marks. These tests were performed using the grouped inhibition variable (CI_Grps), the dimensional inhibition variable (CI), the grouped mental effort variable (Grp_CL), the dimensional mental effort variable (Dm_CL), and the overall achievement variable (Ov_Achieve). Table 6.14 provides an overview of the ANOVAs relating to the grouped inhibition tests.

Table 6.14 Overview of ANOVA findings for overall inhibition X overall cognitive load X overall achievement marks

<table>
<thead>
<tr>
<th>Variables tested</th>
<th>ANOVA Finding</th>
<th>Hypothesis Supported?</th>
</tr>
</thead>
<tbody>
<tr>
<td>CL_Grps x Grp_CL</td>
<td>( F(110, 1, 3) = 1.02, p = .31, \eta^2 = .09 )</td>
<td>No</td>
</tr>
</tbody>
</table>
6.9.1 Summary of findings for the seventh hypothesis

Little support is evident for the hypothesis that a significant interaction exists between inhibitory function, mental effort, and achievement from these findings. At the individual teacher level, interactions between grouped inhibition and grouped mental effort for each teacher did reveal a single significant finding for T3, and what seems to be a clear direction for T1. However, these findings were not replicated when the dimensional forms of inhibition and mental effort were used. In addition, when tested at the overall sample level, neither the dimensional or grouped variables returned significant findings. The only variables to return significant findings again here (for T1 & T3) were the dichotomised variables (CI_Grps & T1 – T4_CL), which had proven stronger for the individual teachers and for the overall relationship between inhibitory function and mental effort in relation to the second hypothesis. The grouping of inhibition into more and less able inhibitors, as well as the grouping of cognitive load into a high and low experience of mental effort, may reveal a valid differential for the way these variables are able to exert an influence within the current student sample. The possibility that these findings signify a genuine first order interaction, however, is limited by the fact that no significant sub-effect contrasts, or even directional interactions, were found in these analyses.

It may be that the lack of observational consistency, or perhaps the way in which the instructional elements relating to the achievement tasks were operationalised in a purely linguistic format, have made it more difficult to determine a genuine interaction between inhibition, mental effort, and achievement in the present findings. The oppositional pattern between inhibition and mental effort, observed in the findings relating to hypothesis two, is highly noticeable, and suggests some sort of interaction between these two factors in
relation to learning-related processing tasks. As well, although little significance was clearly demonstrated for the seventh hypothesis, the patterns of interaction between inhibitory ability, mental effort grouping, and achievement for each of the four teachers seems to display discernable differences between the teachers, and suggest that a predictable relationship may be occurring.

6.9 Summary and conclusions for the data analyses

Summing up the results of these analyses, it may be said that WM function represents a critical element in the educational outcomes of the learner. In this study, a clear relationship is established between WM function and achievement for the students. In addition, a strong generalised relationship appears to exist between student inhibitory function and the amount of mental effort experienced in relation to learning tasks. This relationship can be clearly seen in the correlational and ANOVA tests using both the dimensional and categorical versions of these factors. As well, there is some support for the notion that these factors interact in relation to the level of achievement obtained by individual learners, with some indication that more-able inhibitors tend to achieve higher outcomes and to experience less mental effort in doing so.

What cannot be said is that the relationship between inhibition, mental effort, and achievement is clear and consistently significant. More will be said about this unrequited hypothesis in chapter seven (Discussion and Implications). At this point, it is open to argument that the way the instructional elements were conceptualised in relation to inhibition and mental effort, and low inter-rater agreement reached for the observations relating to these hypotheses, or both, may account for the nonsignificant results obtained for Hypotheses 3-6.

In light of this possibility, a visual look at the overall relationships between inhibition, mental effort, and achievement are offered in figures 6.8 and 6.9. These figures appear to reveal a fairly consistent relationship for inhibition in relation to mental effort, and suggest that these two factors have influenced the median point level of the achievement scores distribution for the current student sample.
Figure 6.6 depicts the relationship between grouped inhibition (CI_Grps), grouped overall cognitive load (CL_Ov_Grp), and overall achievement outcomes (Ov_Achieve) for the study. This figure suggests that, overall, students who experienced greater mental effort tended to achieve lower outcome marks, albeit not at a statistically significant level. The role of inhibition is less clear in this figure, and may be influenced by the findings for T1. However, although not significant, there may be some triangulation occurring between inhibitory group, mental effort, and median score achievement outcomes. Although achievement was not consistent for either the “Hi” or “Lo” cognitive load groups or the “More-Able” or “Less-Able” inhibition groups, it is apparent that both inhibition groups averaged a slightly lower achievement level when experiencing greater cognitive load (57.2), than when experiencing less cognitive load (58.2).

Figure 6.6 Estimated marginal means for overall achievement in relation to CL_Ov_Grp and CI_Grps.
Figure 6.7 shows that the mean achievement scores are the point at which inhibition and mental effort seem to interact with one another. Again, though no significant interaction effect is occurring in the current study, this figure seems to indicate that an interaction trend may be occurring between inhibition, mental effort, and achievement. This type of interaction supports the grouping of students according to inhibitory processing ability and experienced cognitive load, and offers indirect support to the fundamental thesis notion that inhibition provides a causal mechanism by which the amount of cognitive load experienced in relation to achievement may be explained in terms of the information processing model of learning. This causal relationship would be expected to pertain most clearly to extraneous cognitive load, but the lack of support for instructional encoding in the current study leaves this interpretation incomplete. More study of instructional encoding for future research is needed before this particular set of relationships can be verified.

![Graph showing mean achievement scores as the point of interaction between inhibition and mental effort.](image-url)
6.10 Limitations of analyses

Several issues may have contributed to the unsuccessful findings relating to the study, including semantic conceptualisations, differences in the teachers’ instructional encoding, the particular scoring method used for the OSPAN in the current study, and the use of classroom achievement outcomes in lieu of a standardised approach. All of these issues would be expected to influence the ability of these analyses to evaluate study data in the most veridical manner. As well, the analyses are also not able to account for differences in curriculum content between the teachers, which may also be affecting the achievement outcomes for the different students, irrespective of the students’ processing abilities. Another concern may be in the statistical tests themselves. There were a number of statistical tests used to analyse the study data, and some of these may have involved redundant information. This being the case, it is accepted that the overall findings for the thesis are to be interpreted as tentative only, and that once some of the conceptual issues have been better clarified, future research in the area will be able to simplify the statistical requirements.

Scoring of the OSPAN may have diminished some of the processing differences between students, especially the specific levels of accuracy achieved by individual students, by not focusing on the differences in error types that individual students made during the OSPAN task. In a more stringent scoring approach, it might be possible to more clearly identify individual error types, and use this information to clarify the inhibition and mental effort cut-off boundaries. This might deliver a more precise analysis of the grouping influences, and thereby result in more representative groups being formed for the analyses.

Clearly, a larger student sample would have increased the overall power of these analyses. Some tests required homogeneity and specific distribution characteristics that are harder to meet with smaller sample sizes. As the number of overall students included in the study was moderate, the correlational outcomes and some ANOVA findings were quite able to accurately assess this data. Yet the dichotomisation process limited the number of individuals who might appear in any given cell for some of these analyses, and this produced a problem of power, especially in relation to post hoc testing. A larger number of students is needed to overcome this limitation.
This same principle applies to the teachers involved in the study. A greater number of teachers, although quite costly in terms of practical effort and expenditure, would provide for a more robust comparative analysis of the factors relating to instruction and achievement. Also related to the teachers, it may be that, irrespective of its own inherent biases or shortcomings, the use of a standardised test as the primary measure for achievement would produce achievement distinctions that could be more clearly related to the inhibition and mental effort measures.

A statistical limitation with respect to the current investigation may concern the non-orthogonal relationship between some of the variables of interest. For example, the inhibition and cognitive load data both involve the use of executive WM function. In this respect they both overlap somewhat in what they are measuring. This overlap may have limited the ability of the current methodological design to clearly separate the influence of these two variables in relation to many of the other variables of interest within the study, making it more difficult to establish a clear causal pathway for the current analyses. A design that utilises multiple measures of these variables, and perhaps includes biophysical measures of the particular indicators of inhibition (which some EEG or fMRI measures claim to do, cf. Casey, Thomas, Welsh et al., 2000; D’Esposito, Postle, Jonides, & Smith, 1999; Hazeltine, Poldrack, & Gabrieli, 2000; Mattler, 2006; Posner, Peterson, Fox, & Raichle, 1988), might be able to differentiate the inhibitory influences involved in the students’ processing abilities with greater confidence.

Overall, and in spite of these limitations, the results presented in this chapter demonstrate the existence of a generalised relationship between inhibitory processing function and mental effort in relation to learning. These analyses also provide evidence that this relationship affects cognitive processing in a way that influences the learner’s ability to achieve task-related outcomes. Most importantly, the findings suggest that cognitive load may be explained in terms of individual inhibitory ability and the effect that inhibition exerts within the overall processing demands of a situation. The next chapter will discuss these findings in relation to information processing theory and suggest the implications this has for classroom learning and teaching.
CHAPTER 7: DISCUSSION

Researchers have to know something about the brain because the brain constrains the nature of the cognition that it makes possible (Byrnes & Fox, 1998, p. 308).

7.0 Introduction

This thesis represents an attempt to explore effective pedagogy from the perspective of information processing theory. This is because pedagogy is the main focus of all teaching, placing as it does importance on the processes through which knowledge is constructed, produced and critiqued, and recognizing that what is taught and how it is taught are inseparable. One of the goals of a scientific approach to pedagogy is to describe the general principles by which learning occurs. This is especially true in relation to principles that govern the relationship between information processing and classroom instruction, as this juncture forms a key area of understanding for cognitive approaches to pedagogy. This study investigated the relationship between cognitive inhibition and cognitive load (mental effort), as experienced in relation to classroom learning by a group of year-8 students. The problem identified by the thesis was that cognitive approaches to instructional design, although taking into account irrelevant processing and mental effort, have neglected the role of inhibition as a moderator of mental effort in relation to the processing of extraneous load factors, such as instruction. It was determined that an investigation of the relationship between inhibition and mental effort was worthwhile because it would provide valuable information to the area of cognitive instructional design - in particular Cognitive Load Theory, and that the investigation would need to explore and analyse the following:

- whether student inhibitory ability was significantly associated with the experience of mental effort in relation to learning,
- whether this relationship interacted with the way different teachers encoded irrelevant information in relation to classroom teaching, and
- whether the relationship between inhibition and cognitive load interacted to moderate the learning outcomes achieved by the students.

The primary question addressed by the research was whether differences in individual students’ inhibitory function produced corresponding differences in the way the
students experienced mental effort. Related to this were questions concerning whether the instructional encoding of different teachers affected the way individual learners rated their experience of mental effort between the teachers, and whether an interaction occurred between inhibition, mental effort, and instructional encoding that influenced achievement outcomes to a significant degree.

7.1 Hypothesis summary and overview

From the aims and questions of the investigation, a methodology was developed to collect and analyse inhibition, mental effort, instructional, and achievement information in relation to a sample of year-8 (8th grade) learners and four teachers who taught them in common. At the heart of this methodology was a series of predictive hypotheses proposed for testing the assumed relationships. It is important to highlight that these hypotheses are viewed as extending and elaborating one another, building progressively from the underlying concept of inhibition as an executive WM function which modifies the experience of mental effort in relation to learning, to achievement as a product of the influence of inhibition upon mental effort in relation to learning.

Laying the groundwork for these predicted relationships, the initial hypothesis was intended to support the study’s focus on WM as a mediator of individual differences for learning, an understanding of WM based on information processing theory and the concept of WM as a limited capacity system. The second hypothesis elaborated the WM construct, by highlighting the particular role of inhibition as an executive WM function, and by suggesting that this processing function accounts for much of the mental effort required to process learning-related information within the limited capacity of the WM system. This hypothesis proposed that inhibition acts as a moderator upon mental effort in relation to learning. The following four hypotheses (H3 – H6) extended this moderation hypothesis, by testing the notion that linguistic differences in instructional encoding (i.e., instructional priming) can produce corresponding differences in the amount of mental effort experienced by the learner, due to differences in the amount of inhibition required. Each one of these four hypotheses tested this assumption in relation to a specific, language-related encoding element. Finally, the seventh hypothesis further elaborated the initial moderation hypothesis, to include the achievement outcomes produced by the students. Here the assumption was that the moderation of mental effort by individual differences in inhibition
would interact with the instructional encoding of the teachers, to account for a significant part of the students’ overall achievement patterns.

This research can be characterised as both exploratory and applied (cf. Gall, Gall & Borg, 2007; Schultz & Hatch, 1996): Exploratory in that these hypotheses were designed to investigate an area with little prior research (the relationship between inhibition and cognitive load within an authentic classroom setting), and applied in that each of these hypotheses was designed to predict - and thus explain - general relationships operating within that area. Chapter six of the thesis presented the specific outcomes and raw data for each of the hypotheses. It is acknowledged that the strength of these outcomes varied, from little to no significance ($H_3 – H_7$) to highly significant ($H_1 & H_2$). However, a closer look at how these findings are interpreted in relation to the goals and aims of the study, as well as in relation to the theoretical framework and practical implications of the thesis, will now be undertaken to provide a meaningful discussion of what the study might signify to instructional designers, and to educators in general.

7.2 Overview of study findings

The results of this investigation can be summarised by stating that the role of WM as a sort of “gatekeeper” for learning, as indicated by prior research, has been largely supported by the findings relating to the present study, and that inhibitory function, as an aspect of executive WM, does appear to function broadly and significantly as a moderator of mental effort in relation to learning. What has not been supported here is the notion that specific instructional encoding elements can be pinpointed to the relationship between inhibition and mental effort, or that a significant interaction occurs between inhibitory ability, mental effort, and learning achievement. In terms of the instructional encoding elements, some support was indicated for teachers T1 and T4 in the present study, but only the encoding of RELEVANCE by T4 received notable support. In relation to the seventh hypothesis (concerning an interaction occurring between inhibition, mental effort, and achievement), although interactions between grouped inhibition and grouped mental effort at the individual teacher level did reveal a single significant finding for T3, neither the dimensional nor grouped variables returned significant findings when tested at the overall sample level.
Of special interest to the second hypothesis is that the grouping of inhibition into more and less able inhibitors, and the grouping of cognitive load into high and low mental effort, were both supported by the higher levels of significance received across the study when the dichotomised versions of these variables were used. This lends validity to the inverse relationship posited between inhibition and mental effort in the present study, and highlights that both inhibition and cognitive load may be viewed as continuums that contain qualitative thresholds that differentiate between levels of ability or experience. Table 7.1 summarises each of the study hypotheses in relation to its significance outcome.

**Table 7.1 Summary of research hypotheses in relation to significance outcomes**

<table>
<thead>
<tr>
<th>Hypothesis</th>
<th>Significance Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>H₁</strong>: That a significant, positive relationship exists between WM function and student achievement outcomes.</td>
<td>Correlations between RECALL and ACHIEVE, and between ACCURACY and ACHIEVE were significant, as were the between-subjects effects for RECALL and ACHIEVE. Between-subjects effects for ACCURACY and ACHIEVE suggested a supportive trend.</td>
</tr>
<tr>
<td><strong>H₂</strong>: That a significant generalised relationship exists between student inhibitory ability (CI scores) and student cognitive load (CL ratings for the instruction they receive).</td>
<td>Correlations between inhibition and mental effort were significant for 3 out of 4 teachers, and analyses of inhibition and mental effort as generalised variables received strong support in both dimensional and categorical terms. In addition, the predicted direction of this relationship was supported.</td>
</tr>
<tr>
<td><strong>H₃</strong>: That a significant interaction exists between the students’ inhibitory ability (CI), cognitive load ratings (CL), and the way the teachers encode instruction for relevant vs. irrelevant information.</td>
<td>A significant, first order interaction was found to occur between inhibitory group, mental effort, and the encoding of RELEVANCE for teacher T4, with a possible trend occurring for T1. No significant interactions were found for teachers T2 and T3.</td>
</tr>
<tr>
<td><strong>H₄</strong>: That a significant interaction exists between the students’ inhibitory ability (CI), cognitive load ratings (CL), and the way the teachers ask questions in a way that gives irrelevant or distracting semantic cues to the students.</td>
<td>Although a possible trend may be occurring for T1, no significant first order interactions between inhibitory group, mental effort, and the encoding of CUE were found for teachers T2 – T4. No between-subjects effects were found for any of the variables.</td>
</tr>
<tr>
<td><strong>H₅</strong>: That a significant interaction exists between the students’ inhibitory ability (CI), cognitive load ratings (CL), and the degree to which the teachers use words with multiple referents available.</td>
<td>No significant, first order interactions between inhibitory group, mental effort, and the encoding of VALENCE were found for any of the teachers, and no between subjects effects were found for any of the variables.</td>
</tr>
<tr>
<td><strong>H₆</strong>: That a significant interaction exists between the students’ inhibitory ability (CI), cognitive load ratings (CL), and the degree to which the teachers make only weak semantic associations to technical or jargon words.</td>
<td>No significant interactions were found in relation to inhibition, mental effort, and the instructional encoding of JARGON for any of the teachers, although a between subjects direction may be occurring for inhibition in relation to JARGON for T4.</td>
</tr>
</tbody>
</table>
7.3 Theoretical implications of the findings

At the theoretical level, there are at least three clear implications from these findings:

1) That educational designers should continue to utilise the concept of a limited capacity WM system as a construct core to the design of cognitive instructional strategies,

2) That the inhibitory function needs to be considered as a moderator of mental effort in relation to instructional design, and

3) That the specific role of inhibition needs to be further investigated with respect to how it interacts with attentional processing in relation to instructional delivery.

7.3.1 Support for the construct of WM

Findings from prior research have established that individual differences in WM ability are highly correlated with differences in learning outcomes. On this basis the first hypothesis of the thesis predicted that a significant, positive relationship would exist between WM function and student achievement outcomes. Significant relationships were found for scores relating to both the passive, short-term storage (RECALL), and active, problem-solving (ACCURACY) functions of WM in relation to student achievement (ACADEMIC). These findings support the first hypothesis of the research, and are in agreement with a body of information that indicates the importance of WM to learning (for a review of such information see Conway, Kane, Bunting, et al., 2005).

A clear implication of the findings for the first hypothesis is that, in order to support effective learning, instructional designers (including the classroom teacher) need to be aware of the degree to which WM function can act as a processing gatekeeper for learning. In this respect a foundational notion for the current research has been that an understanding of WM is crucial to the design of an efficient and effective instructional pedagogy,
including the strengths, limitations, and distinctive functions of the system. The present findings provide ongoing support for this understanding, and highlight the centrality of WM as a theoretical construct important to instructional design. The findings from the first hypothesis thus form an important contribution to the validity of the current thesis.

7.3.2 Inhibition and mental effort

The study’s specific focus on inhibitory function is an extension of the understanding of WM as a complex yet limited capacity processing system, and is based on the distinction commonly made between different aspects of WM that relate to either a more passive (storage) function or to a more active (attentional) processing function, with the attentional processing function being viewed as being supported by executive components. In line with this, the second hypothesis predicted that a significant relationship would exist between student inhibitory function (CI) and the cognitive load (CL) ratings assigned by students to their learning, on the basis that inhibition, as an executive WM function, acts to moderate the amount of mental effort experienced in connection to learning. An important feature of this hypothesis was that the relationship was predicted to be positively signed, yet on the basis that the measures used to elicit inhibition data (the CI scores) and mental effort data (the CL ratings) were inverse to one another.

The inverted nature of this relationship formed an important part of the theoretical understanding for the study, with the second hypothesis expressing the expectation that less efficient inhibitors would experience greater cognitive load in relation to their learning while the more efficient inhibitors would experience less cognitive load in relation to their learning. Although, overall, mixed results were obtained for the teacher-specific CI x CL correlations, significant CI x CL relationships were found for the current student sample with respect to three of the four participating teachers, supporting the hypothesised relationship between inhibitory efficiency and cognitive load. This suggests that a notable and generally consistent connection does exist between inhibitory function and mental effort in relation to specific classroom learning contexts.

These findings support the second premise of the study: That inhibitory function accounts for a significant proportion of the cognitive load experienced in relation to
learning. The interpretation posited here is that much of the mental effort experienced in connection to learning stems from the need to inhibit task-irrelevant information during the processing of learning-related instruction. This interpretation is in accordance with schema theory and information processing theory, both of which view WM as having discriminatory or “executive” mechanisms which support attentional processing by allowing the individual to focus on task-relevant information while simultaneously suppressing interference from task-irrelevant information. The findings for the second hypothesis are thus interpreted as indicating that inhibition does exert a moderating influence on the amount of mental effort experienced in relation to classroom learning.

These findings may also provide a causal mechanism by which the nature of extraneous cognitive load can be explained. One of the chief criticisms of cognitive load theory is that it appears tautological and is not amenable to empirical testing, because the explanatory relationship between mental effort and WM capacity has been presented in a manner that is too broad and generalised. The notion that a direct relationship exists between inhibition and mental effort offers a means of testing this relationship more specifically, and thereby may offer an explanation of cognitive load theory that is more empirical and sufficient to the purposes of the theory.

In light of this interpretation, the significant relationship found for the CI scores in relation to word recall may also be noteworthy. This relationship indicates that the role of inhibition is important to the processing of task-relevant information as well as to the processing of irrelevant information, and suggests that inhibition provides a generalised moderating effect on the process of selective attention. In addition, a significant correlation occurred between the students’ inhibitory distribution (CI_Dm) and their overall achievement distribution (Ov_Ach, \( r_{[14]} = -.29, p < .01 \)), demonstrating that this effect does impact upon learning outcomes, albeit not necessarily via the influence of mental effort. That inhibition provides a generalised moderating effect on the process of selective attention is also suggested by Bjorkland and Harnishfeger (1990), and Dempster (1991; 1993), and may support a second contention of cognitive load theory: That essential or “germane” cognitive load pertains to the encoding of task-relevant information, and plays a constructive role in the learning process.
7.3.3 An interpretive position for the moderating role of inhibition

The notion that inhibition may be connected to mental effort is not an entirely new concept (cf. Berninger, 1999; Davies, Jones, & Taylor, 1984; Kahneman, 1973; Neill, Valdes, & Terry, 1995). Yet, as far as the current author is aware, the idea that differences in mental effort can be systematically associated with differences in inhibitory ability has not been specifically addressed by prior research. For this reason a discussion of the thesis’ particular understanding and interpretation of the moderating role of inhibition appears in order.

The moderating role for inhibition appears to be directly implied by the significant findings of the current study, as discussed in relation to the second hypothesis. Yet this role may also be indirectly supported in that the students’ inhibition (CI) scores related negatively to their mental effort (CL) ratings for the OSPAN itself ($F_{82} = -1.82, p < .05$). The negative relationship between inhibitory ability and mental effort on the OSPAN suggests that the specific role of inhibition is somehow inversely related to the amount of mental effort required to perform complex, multi-task activities (such as the OSPAN), which require sophisticated inhibition of incongruent, task-irrelevant information concordant with extended representational holding. This accords with the thesis’ understanding of inhibition as a comprehensive, domain-general executive WM function, which supports attentional processing by restraining the activation of irrelevant information stored in short-term memory while also suppressing partially activated (distracting) information already attentionally activated. If this interpretation is transferred to the CI x CL relationships found within the context of classroom learning, it further suggests that the less efficient inhibitors struggled more with instruction they perceived as more complex or perhaps less well organised than did the more efficient inhibitors, because they found it more difficult to maintain the level of inhibitory constraint required.

In this respect, it is of interest that the strongest teacher-specific CI x CL relationship occurred for T1, the teacher observed as encoding least clearly on three out of the four instructional encoding elements. It appears that the students felt they had to work hardest under this teacher’s instruction. In line with the proposed role of inhibition as an executive function that suppresses irrelevant and conflicting information, what may have
been occurring is that this teacher did not format task-relevant information as clearly as the other teachers, and perhaps incorporated irrelevant information at a higher level than the other teachers. From the thesis point of view, poor instructional formatting affects the level of conceptual formatting taking place during the learning task because it activates schematic information inconsistently. One interpretation of this CI x CL relationship is, therefore, that T1 was activating schematic information with greater ambiguity then the other teachers.

This interpretation appears reasonable in light of the actual number of more-able versus less-able inhibitors who also experienced high or low cognitive load under the instruction of T1, as depicted in figure 7.1. Note that there are a relatively large number of less-able inhibitors assigned to the higher cognitive load group (4.1 – 7.0), with very few of the more-able types in this group. Conversely, there are more of the more-able inhibitors assigned to the lower cognitive load group (0 – 4.0), with fewer of the less-able types in this group. This grouping effect is in line with the thesis prediction made for hypothesis two, but was not as clearly differentiated for the other teachers as it was for T1. Figure 7.1 suggests that the polarity for this effect was more extreme for this teacher, that is, something about learning under the direction of T1 was causing students with less inhibitory ability to experience a markedly higher cognitive load during the instructional tasks in comparison to the more-able inhibitors. Although not statistically significant, when taken in conjunction with the instructional ratings observed for T1, this may indicate that a greater level of ambiguity was present in the instructional delivery of this teacher, a position which offers some support for the current thesis.
7.3.3.1 Inhibition in relation to instructional ambiguity

When posing this interpretation of the study data, reference is also made to the notion of instructional ambiguity as reviewed earlier, in connection with Pascual-Leonne’s theory of “constructive operators” (cf. chapter 3, pp. 26 - 28). This theory offers a conceptual framework for investigating the impact of instructional ambiguity upon learning in that it provides for what is termed the “dimension of interrupt operations”. Pascual-Leonne proffers this dimension as the inhibitory mechanism of WM, which works to either support processing limitations (by facilitating schematic processing), or to overwhelm these limitations (by misleading schematic processing). Interrupt operations can thus be used to define the degree to which instructional strategies prime for appropriate schematic processing relative to the learner’s developmental “M-space” (Pascual-Leonne’s term for the area of selective attentional focus, and consisting of task-relevant schemata that are fully activated and positioned to control the processing, cf. Pascual-Leonne, 1980; Pascual-Leonne & Johnson, 1999). Of interest is that misleading instructional strategies are seen as necessitating greater inhibition of incongruent, task-irrelevant information and extended representational holding, because they tend to activate
schemata which are only weakly associated to the task while at the same time only partially activating task-relevant schemata. Thus, misleading instructional strategies are those strategies which promote the spread of activation too broadly for the limited “M-space” of the learner.

From this position, the current thesis proposes that effective learning depends on teaching that has made targeted use of schematic priming. Although not supported by all the findings of the present study, this proposal is in accord with the underlying concept of instructional encoding as put forward by the thesis, and, it is suggested, demonstrated to some degree in the findings for T1. This proposal involves a set of relationships wherein the type of instructional priming involved in a learning situation (misleading or facilitating) is seen to affect inhibitory efficiency, and may be construed to some degree from the amount of mental effort experienced by the learner. It is acknowledged that whether or not the theoretical logic of this position appears tenable, the ability to construe instructional priming from a measure of mental effort remains problematic from the findings of the current study. However, in this study the encoding of specific language elements was used to test these relationships, and the observational concordance for the teachers’ use of these elements was not strong. It may be that a broader, more generalised operational definition for priming is required, and that evidence be drawn more widely from the teacher’s use of such things as analogy, metaphor, visual aids, advance organisers and thematic integration.

Pasucal-Leonne’s notion of interrupt operations seems relevant to the current thesis because it suggests a mechanism by which ambiguous instructional situations are able to place a higher cognitive load on the limited capacity of WM. According to the thesis, this occurs because ambiguous (misleading) instructional situations prime for greater accommodation of the information, a type of processing that maximises attentional interruptions and requires greater mental effort at the WM level of processing. In contrast to this, unambiguous (facilitating) situations prime for greater assimilation of the information, a type of processing which minimises attentional interruptions and requires less mental effort at the WM level of processing. This hypothesised set of relationships is depicted in figure 7.1. Note that this depiction represents an extrapolation of the dimension of inhibitory efficiency as shown in figure 3.1 of the literature review, and is
applied here to the specific correspondence hypothesized for inhibition in relation to cognitive load.

![Figure 7.2 Proposed set of relationships between inhibition, mental effort, and instructional priming.](image)

What the current study adds to Pascual-Leone’s concept of interrupt operations is the notion that mental effort actually affords a measure of the relationship between inhibition and instructional ambiguity, with the amount of ‘misleading’ or ambiguous instructional encoding being evident from the amount of mental effort required to process the learning-task information. Further research looking more specifically at the role of priming in relation to instruction may shed greater light on these relationships. However, from the current findings it is proposed that inhibition, as it acts to suppress task-irrelevant information within the limited capacity WM system, does serve to function as a moderator of mental effort in relation to classroom learning. This role for inhibition is put forward as a basic principle for the design of efficient instructional strategies, and will be applied to two original strategies in section 7.4.3. However, what also needs to be discussed in relation to these findings is the extent of the moderating effect for inhibition. This is important because the role of inhibition appears most relevant for extraneous cognitive load, and is, therefore, not viewed as the sole or comprehensive explanation for the amount of cognitive load experienced in relation to these findings.

### 7.3.4 Extent of the moderating effect for inhibition

The very notion of selectivity in the processing of information requires that we consider how some of the information becomes suppressed. The thesis has posited
schematic activation as the basic process by which information associated to a learning task becomes activated for attentional processing. It has further proposed that inhibition then acts to support attentional processing by suppressing non-associated and weakly associated information from the processing, in order to stop this information from interfering with the attentional processing goal.

This part of the discussion will begin by recapitulating the statistical outcomes for inhibition in relation to mental effort, and then proceed to discuss these findings in terms of their significance levels and effect size, and what these may mean in relation to the thesis position. For this discussion note that significance refers to the probability that a finding occurred by chance, and is indicated by the alpha level set to test this probability (.05 for the current study). Effect size refers to the strength of a variable relationship, and is generally taken to indicate the proportion of one variable which is accounted for by differences in another variable. Cohen (1988) defines correlational effect sizes ($r^2$) as corresponding to small (.2), medium (.5), or large (.8) associational effects. He suggests that ANOVA effect sizes ($\eta^2$) should be viewed as small (.01), medium (.06), and large (.14), but also advises that these effect size guidelines are to be judged only in relation to the circumstances of a particular study, including overall findings and power.

Table 7.2 summarises the levels of significance and effect sizes found for inhibition in relation to mental effort for the current study. Notice that most of the findings were statistically significant, that is, there was less than 5% probability that they occurred by chance. The strength of this association ranges however, from .03 to .19 for the teacher-specific correlations, and from .10 to .12 for the overall variable correlations. Following Cohen’s effect size definitions, this suggests that the relationship between inhibition and mental effort is small. Yet the between-subjects analysis of inhibition in relation to mental effort suggests this is a moderating relationship, and that a reasonable (small to moderate) amount of the mental effort experienced in relation to learning was accounted for in the current study by the inhibitory abilities of the participating students. Therefore, even though the moderating effects of inhibition may not be strong in the current findings, a causal relationship does appear to exist here, with inhibition having exerted a reasonable effect on mental effort.
Table 7.2 Significance and effect size outcomes for student inhibition in relation to mental effort.

<table>
<thead>
<tr>
<th>Type of Variable Relationship</th>
<th>Variables Involved</th>
<th>Relationship Significance</th>
<th>Effect Size (r² range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teacher-Specific Correlations</td>
<td>CI x T1-T4_cg.ld.</td>
<td>T1-T3 &lt;.05; T4 = ns</td>
<td>.04 - .05</td>
</tr>
<tr>
<td></td>
<td>CI_Grps x T1-T4_cg.ld.</td>
<td>T1 &lt;.01; T2 &lt;.05; T3-T4 = ns</td>
<td>.03 - .12</td>
</tr>
<tr>
<td></td>
<td>CI x T1-T4_CL</td>
<td>T1 &amp; T3-T4 &lt;.01; T2 = ns</td>
<td>.04 - .11</td>
</tr>
<tr>
<td></td>
<td>CI_Grps x T1-T4_CL</td>
<td>T1 &amp; T3 &lt;.01; T2 &lt;.05; T4 = ns</td>
<td>.04 - .19</td>
</tr>
<tr>
<td>Overall Variable Correlations</td>
<td>Dimensional = &lt;.01</td>
<td></td>
<td>.10</td>
</tr>
<tr>
<td></td>
<td>Categorical = &lt;.01</td>
<td></td>
<td>.12</td>
</tr>
<tr>
<td>Analysis of Between-Subjects Effects</td>
<td>Inhibition (IV)</td>
<td>Overall = &lt;.04</td>
<td>R² = .32</td>
</tr>
<tr>
<td></td>
<td>Mental Effort DV</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Overall, these findings do appear to support the most original premise of the thesis, that inhibition acts as a moderator of mental effort in relation to classroom learning. Although this position may appear tenuous in light of some of the particular findings for the current study, it is viewed as tenable in relation to the theoretical associations made, and seems clearly supported by the findings relating to the second hypothesis.

7.3.5 Summary of theoretical implications for the findings

The findings relative to the second hypothesis are important because they support the notion that inhibitory function, as an aspect of executive WM, displays a range of individual differences, and that these differences correspond generally and in a significant manner to the learner’s experience of mental effort in relation to their learning. This position is useful because it concerns how pedagogy is inseparable from the cognitive and neurological processes involved in teaching and learning. All teachers must teach to the diversity of the classroom, to the student’s discovery of knowledge, to possibilities of information mapping, to creativity and curiosity, and to the construction of personalised meaning. Yet students are all too often required to process information that is diverse, multi-layered, and often conflicting during their classroom learning. The result of an inefficient pedagogy is that many students will respond with shallow learning, disallowing the learner from forming connections essential to the development of meaning and the encouragement of lifelong learning. What the current findings suggest is that the adoption
of a more holistic pedagogy, one that takes into account the way instructional strategies impact upon the informational connections being made and primed for, will foster a more efficient and integrated, deeper learning.

The present findings also suggest that at the heart of effective instruction lies a dynamic tension between what students do to enrich the information involved in their learning and what the teacher has done to determine how that information is organised, presented, and connected to the student’s existing knowledge. Inhibition appears to play a pivotal role in bridging the tension that can exist between how the learner is able to enrich information and how the teacher organises the information. The thesis suggests that by moderating mental effort, inhibition provides a nexus between the teacher’s pedagogical ability and the student’s cognitive ability that is measurable via the level of mental effort involved in task-related processing. In this respect the current thesis applies the notion of individual differences to inhibitory ability, and suggests that instructional designers who take note of this aspect of individual differences will be better equipped to design more efficient - and therefore more effective - instructional strategies. In response to this suggestion, a key question is how these theoretical implications might be applied at the classroom level. Answering this question in an applied manner is a central goal of the research, and forms the focus for the following section.

7.4 Practical application of the findings

Two important meta-analyses in terms of effective teaching and learning are those performed by Hattie, Biggs, and Purdie (1996), and that of Marzano (1998). Although Hattie, Biggs, and Purdie identified more than 21,000 different studies concerning research into various aspects of teaching and learning at the time of their analyses, they confined their own examination to 51 separate “learning skills interventions”. They found instructional strategies aimed at single-skill outcomes to be more effective, with those that focus on individual techniques to encourage memory and “reproductive performance” working best. This aligns with the current set of findings in that memory enhancing strategies tend to reduce the amount of representational holding required during the learning task. Marzano (1998) examined data aggregated from more than 100 studies, including primary, secondary, and college level learning. He specifically highlighted the role of metacognition for effective learning, and noted that cognitive strategies which
emphasise experimental enquiry and idea representation, as well as the teaching of specific cognitive techniques such as using prompts and cues to aid information recall, and using questions to support elaboration, provide the best types of scaffolding for metacognitive function. This is a clearly constructivist teaching approach, and illustrates the importance of information priming in that it stresses the use of prompts and cues to encode for positive, task-relevant priming, and the use of metacognitive elaboration to direct the activation of task-relevant schemata.

What is important to the current study is that each of these meta-analyses acknowledged the contribution to learning made by effective cognition, and that each emphasises memory, prompting and cueing, elaboration, and idea representation as instructional approaches that promote effective academic cognition. In this respect both analyses can be connected to the current research because both posit instructional strategies that would naturally involve priming and inhibition. However, neither analysis acknowledges the role of priming or inhibition directly, so it is also important to note Goswami’s (2004) assertion that translating neuropsychological research into an educational understanding of cognitive instruction remains largely problematic. In this respect, Byrnes and Fox (1998), who made a detailed overview of the educational relevance of research in cognitive psychology and cognitive neuroscience, described the situation similarly:

*In recent years, a growing number of cognitive psychologists have recognized that the division between researchers who study cognition and researchers who study brain processes is no longer helpful...Given the close historical correspondence between developments in cognitive psychology and developments in educational psychology, many educational psychologists are making the same arguments regarding the potential “information value” of research in cognitive neuroscience...In particular, these scholars contend that the time has come to use the findings of cognitive neuroscience to transform the field of educational psychology...we make the case that research in cognitive neuroscience has a great deal of information value for educational psychologists if it is interpreted appropriately.* (p. 298)

The point being made by both Goswami, and Byrnes and Fox, is that irrespective of insightful research and meta-analyses that identify the “best practice” principles and strategies relating to cognition, a common problem persists in translating research insights into classroom practice. In light of this, a clear aim for the current thesis must be that the study outcomes relating to inhibition and mental effort are translated appropriately into instructional strategies and approaches that are able to account for the influence of
inhibition in relation to mental effort. In accordance with this, the following section will examine ways in which to apply the cognitive and neuropsychological insights gained concerning inhibition within a classroom educational context. This is not only considered important in light of the assertions made by Goswami and by Byrnes and Fox, it is also necessary because the classroom teacher bears a significant responsibility to instruct in such a way as to evoke “best practice” learning across the range of individual differences that characterise an average classroom. According to the current findings, best practice learning will occur when the influence of inhibition is taken more fully into account when designing instructional strategies and approaches.

7.4.1 Developing an appropriate cognitive pedagogy

A cognitive view of learning emphasises that effective teaching requires the teacher to understand and use instructional strategies that scaffold for efficient information processing (cf. Block & Pressley, 2002; Rosenshine, 1997). In line with this, the current thesis has postulated that the development of an appropriate cognitive pedagogy requires instructional designers to consider how learning-related schematic activation may be affected by instructional ambiguity. The essential premise put forward was that as instructional ambiguity varies, so does the amount of inhibitory function required to support attentional processing, because inhibition moderates the amount of mental effort in response to the level of ambiguity (facilitating or misleading) that exists in the associated instruction. The resulting assertion is that instructional designers who consider the moderating role of inhibition will be better equipped to design non-ambiguous instructional strategies than designers who ignore this role.

In order to translate this assertion into an appropriate educational application, a number of strategies to control for instructional ambiguity and limit the amount of cognitive load experienced in relation to learning will be discussed. This discussion will begin by reviewing instructional strategies nominated as providing effective information processing. It will then proceed to discuss the use of two original strategy approaches viewed as connected specifically to the current study findings.

7.4.2 Current information processing strategies
According to Alexander and Murphy (1998), and Jonassen and Carr (2000), there are three broad cognitive instructional approaches that utilise strategies designed to enable efficient learning: approaches that clarify the information, approaches that summarise the information, and approaches that get students to make predictions about the information. The common denominator between all these approaches seems to lie in the way new information is linked to existing knowledge (cf. Derry, 1996). Yet of interest to the current thesis is how each approach might also work to minimise the use of inhibition.

Clarifying strategies involve the use of problem-based learning approaches, and are designed to get the student asking questions about the information. This type of instructional approach can be expected to scaffold for more efficient use of inhibition because it elaborates the information. Elaboration that is organised in a relevant and integrated manner refines the activation of relevant schemata by emphasising the parameters of attentional focus, thus minimising the need to suppress irrelevant information.

Summarising strategies get the student to distil and categorise the information. These strategies help to minimise inhibition in that they rehearse and keep activated the most appropriate schemata, and thereby promote processing automaticity (this is probably the simplest of the three approaches in terms of its effects upon inhibition).

Predictive strategies are more complex, and can be expected to display a sliding scale in terms of the need to inhibit during learning. Initially, predictive strategies will require the student to represent and hold a larger amount of information in short-term memory, making greater demands upon the use of executive inhibition while the student considers different concepts and abstract relationships. At the same time, the activation of non-associated and weakly associated schemata will also be greater (due to the complex amount of conceptual information being considered), and this will also require additional inhibition. According to the current thesis, this approach will be more difficult initially for students with less inhibitory ability, and result in higher levels of cognitive load for these sorts of learners. However, as the student perseveres, the amount of representational holding will decrease, due to a progressive narrowing of attentional focus in response to the elimination of some of the initial hypotheses. Likewise, the amount of irrelevant
activation taking place will also decrease as the number of non-associated and weakly associated schemata becomes fewer. Over time, predictive strategies should prove successful for both high and low inhibitory types, due to their ability to create clearer conceptual relationships for the information. However, initial differences in terms of cognitive load within the classroom should be monitored for this approach, and the use of priming should be closely managed, in order to control for how the strategy is affecting individual inhibitory differences within the class as a whole.

The predictive instructional approach may be related to the thesis’ concepts and findings quite well, because it involves a complex awareness of inhibitory function across the strategy use. For this reason the original strategies presented in section 7.4.3 are proposed in relation to this particular approach. However, before these original strategies can be presented, it is important to establish the broad parameters of existing cognitive instructional strategies, as a sort of overall framework for the proposed strategies. To this end, table 7.3 lists a range of teaching strategies commonly used to operationalise the cognitive approach to learning (cf. Mayer & Moreno, 2003). These strategies are widely used because they are considered effective in promoting attentional focus. In relation to inhibition though, it is important to note that the crucial point is how new information is linked to existing knowledge. For this reason, a discussion of how each strategy might relate to inhibition is included in the descriptions offered below.

Table 7.3 Cognitive instructional approaches according to type, attentional role, and inhibitory relationship

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Type</th>
<th>Attentional Role</th>
<th>Inhibitory Relationship</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Concept Map</strong></td>
<td>Summarising</td>
<td>Visually presents the logical connections &amp; hierarchical organisation for a concept.</td>
<td>Concept mapping strongly activates task-relevant schemata, and involves little activation of irrelevant schemata. Some representational holding is required, but automaticity is also supported, thus a low overall need for inhibition exists with this strategy. Both high and low ability inhibitors should benefit from this instructional approach, as it promotes the understanding of information in terms of propositions and relational meaning.</td>
</tr>
<tr>
<td><strong>Brainstorming</strong></td>
<td>Summarising</td>
<td>Focuses attention collaboratively on generating schematically associated ideas, without stopping to evaluate the truth value of the information.</td>
<td>High activation of relevant schemata, but also activation of irrelevant and only partially associated schemata. Thus a high</td>
</tr>
</tbody>
</table>
**Analogy**  
Summarising & Clarifying  
Focuses attention on the correspondences between different ideas or concepts, in order to clarify new information.  
Moderate to strong activation of task-relevant schemata, scaffolding for cognitive assimilation (rather than accommodation). If the correspondences are not clear however, there may also be significant activation of irrelevant and only partially-relevant schemata. This strategy can, therefore, involve high representational holding and executive inhibition demands. Attention to the organisation and formatting of information is important, and the teacher should look for grouping effects occurring in response to the strategy, as a check on inhibitory demand.

**Revision**  
Summarising  
Scaffolds new learning by forging explicit attentional links to what has previously been covered in an area of study.  
This strategy primes for the activation of task-relevant schemata, involving assimilation of the information and moderate automaticity. Yet elaboration of the information will not occur if revision remains at the rote rehearsal level. Rote rehearsal does not encourage rich associations for the information. Thus even relevant schemata may remain only weakly activated using this approach, and because of this the strategy may necessitate higher inhibition.

**Concept Teaching**  
Clarifying  
Scaffolds for effective accommodation processing by making students aware of the particular features of a given concept. (This strategy falls squarely within the Zone of Proximal Development, as envisaged by Vygotsky, in relation to learning)  
Students with lower inhibitory ability may find this strategy misleading, at least initially. High levels of representational holding coupled to weak initial schematic activation for the concept may make greater demands on the inhibitory function. Explicit concept teaching may be combined with the use of a clear analogy to create a more organised and directed overall approach. Again, the teacher should look for grouping effects as a check on strategy effectiveness for the whole class.

**Advance Organisers**  
Summarising & Clarifying  
Establishes a “big picture” framework, to help students elaborate and make meaningful connections in relation to new learning content.  
Advance organisers prime for assimilation processing, because they make use of analogy to activate task-relevant schemata. If the mapping of new content is not analogised to existing knowledge coherently however, weakly associated and even non-
associated schemata may also be activated, requiring high levels of representational holding and maximising the need for inhibition. Thus this strategy can make either little or high demands on inhibition. The level of demand will depend upon how well the schematic activation is integrated.

<table>
<thead>
<tr>
<th><strong>Graphic Organisers</strong>&lt;br&gt;(e.g., a flow chart)</th>
<th>Summarising &amp; Clarifying</th>
<th>Focuses attention on the processes or relationships relating to information, by presenting a graphic format of how input-process-output occur for an area of learning.</th>
</tr>
</thead>
</table>

Graphic organisers provide a conceptual prompt for the processing of task-relevant procedural information. Yet this can activate both content and process schemata associated to learning, and thus can place considerable demands on representational holding. As well, because the scope of activation can be quite broad, the need to inhibit non-relevant and weakly associated schemata can be significant. This is another strategy where the teacher should look for grouping effects as a check on inhibitory demand, as it is expected that this strategy will work much better for some students (those with high inhibitory ability) than for others (those with low inhibitory ability).

<table>
<thead>
<tr>
<th><strong>Adjunct Spatial Displays</strong>&lt;br&gt;Summarising</th>
<th>Based on processing mode theory. Elaborates attentional processing by presenting information simultaneously in two different visual display formats (e.g., presenting images relating to geography on a screen while also presenting a verbal description of the relevant information).</th>
<th>Mayer and Moreno (2003) view this strategy as important for helping students make meaning from information. Yet this strategy may also create a need for too much representational holding of information, while the student tries to integrate the various presentation modes (what Mayer &amp; Moreno acknowledge as a ‘split attention’ effect). Mnemonic aids may help condense the information, but the teacher will need to ensure that the different presentation modes integrate information coherently, in order to avoid excessive demands being made on inhibition.</th>
</tr>
</thead>
</table>

| **Multi-Modal Presentations**<br>Summarising | Again, seeks to elaborate attentional processing by presenting information in different sensory modes (e.g., presenting geography images while speaking about them, and perhaps also having the students handle geographic artefacts and read ancillary handouts). | This strategy tends to strongly activate task-relevant schemata, and can thus promote elaboration of the information, providing for more meaningful learning. The danger with elaborative strategies, however, is that they can also activate weakly associated schemata, and may only partially activate the relevant schemata. If the use of multiple modes produces too much irrelevant material (background, procedural, or contextual), then the student |
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| Synchronisation | Reduces representational holding by reducing the types of dissimilar formats used in presenting the information (e.g., watching a movie while someone is speaking), and by making certain that presentations are not separated by too much time or too much space. | Synchronisation helps to cut down on representational holding requirements because it integrates the use of multiple presentation modes to offer a more coherent flow of information, which is also elaborated. If the synchronisation is not coherently integrated, however, a split attention effect can occur, necessitating greater use of inhibition. This is a complex attentional strategy. It is capable of delivering quite efficient instructional processing, but requires the teacher to carefully organise and format the information across various modes of presentation, in order to avoid separation of essential mode-specific information. Use in conjunction with advance organisers to maximise the activation of task-relevant schemata, and use mnemonic aids to help condense the information. This will reduce the overall demands being made on both short-term storage and inhibition, and should be taken into account when using this type of strategy. |

| Mnemonic Aids | Summarising | Mnemonics are memory proxies, which encode information within a substitute symbolic structure. Mnemonics reduce representational holding by manipulating the activation of information associations. Various mnemonic aids are utilised in learning, including rhymes, acronyms, and visual images. The common principle seems to be that information structured mnemonically becomes structurally associated with more familiar knowledge, assisting later recall. | Less inhibition will be required once the mnemonic has been learned, because the number of information elements will have been reduced. Yet the initial learning of the strategy itself can involve significant encoding elements, and the teacher should construct clear associations for the mnemonic to reduce this phase of the strategy. As well, some mnemonics are quite rigid (e.g., peg-type, keyword), and this may lead to lower recall if part of the strategy itself is forgotten, or if the contextual prompts and cues change. In this case the need to invoke executive inhibition would increase significantly. For this reason, using mnemonics that are inherently meaningful to the learner is important. |
7.4.3 Original information processing strategies: Proposed implications of the thesis

This discussion will now proceed to discuss the use of two original strategies designed to connect the current study findings to classroom practice. These strategies are proposed in relation to the use of predictive approaches to learning, as this type of approach can be expected to make different early and late inhibitory demands on the learner, due to the narrowing of attentional focus that takes place over time when using this approach. The first of these strategies aims to help the teacher understand and control for misleading processing in relation to the use of early predictive instructional approaches. The second strategy seeks to facilitate processing in relation to later predictive instructional approaches. The common denominator between the two different strategies is that they both aim to account for inhibitory influence in terms of cognitive load theory (cf. Gerjets, Scheiter, & Shuh, 2008; van Merriënboer & Sluijsmans, 2009). Specifically, the aim of these strategies is to:

- Lower the cognitive load on selective attention (by decreasing the amount of incidental processing and information-holding needed to process the information).
- Increase the automaticity of cognitive inhibition (by priming more directly for task-relevant, schematic information).
- Increase the depth of meaningful processing involved in using this strategy (by providing clear schematic organisation).
- Increase the level of self-regulation that occurs in relation to the learning (by connecting the learning to prior knowledge in a systematic manner).

It is important to note that predictive strategies involve a type of progressive learning. This occurs because the student’s efforts to understand and process different predictions about a problem eliminate and refine the predictive elements and information over time. Because of this, there are differences between the amounts of inhibitory activity required to maintain selective attentional focus for early versus later predictive strategy use. According to the inhibition X cognitive load model of attentional processing formulated by the thesis, this means that the amount of cognitive load can also be expected to vary, according to the amount of representational holding and level of schematic activation involved at different times during the progression.
Figure 7.3 depicts the relationship between extraneous cognitive load and the use of predictive strategies. This depiction is based on the inhibition X cognitive load model of attentional processing, as discussed in chapter 4 of the thesis. Note that this relationship is driven by the amount of processing automaticity that is associated with the different phases of the strategy, and that the purposes of priming change with the need to address different processing issues that arise as the strategy progresses. The original strategies for this thesis are offered on the basis of this change, and reflect the fact that different “inhibitory strategies” need to be employed during the early versus late phases of the predictive strategy, in line with the overall effects of automaticity for these phases. The first of these strategies involves the minimisation of misleading instructional influences, and seeks to limit the amount of representational holding and irrelevant activation that occurs during the early phase of prediction. The second strategy involves the elaboration of facilitating instructional influences, and seeks to consolidate and expand the overall learning that has taken place across the strategy.

7.4.3.1 A strategy to control for misleading processing in relation to early predictive instructional approaches

This first strategy is proposed in relation to the use of early predictive approaches to learning. Referring again to Pascual-Leone’s concept of “interrupt operations”,
Misleading situations occur whenever instructional strategies include a significant degree of irrelevant or incongruent information. Inhibiting irrelevant schemata that are activated in this manner make high demands upon the learner’s limited capacity “M-space”, because schemata that are less relevant to the learning task are left to decay and thereby fall outside the field of attentional activation. Cognitive inhibition is needed at this point to ‘interrupt’ selective attention, in order to allow executive capacity allocation to be changed. This allows schemata that are less task-relevant to be suppressed, while at the same time enabling schemata that are more task-relevant to be boosted to the activation threshold. However, interrupting attention makes significant demands upon the attentional resources of M-space (constituting what Pascual-Leonne [1980] calls an “M-capacity task”), and thereby decreases the efficiency of processing overall. According to the thesis, this occurs when instructional delivery cues or primes too broadly, boosting the activation of irrelevant and only partially-relevant schemata.

Misleading processing is not efficient because it requires a great deal of non-essential processing and additional representational holding, in addition to the sophisticated executive inhibitory function required to actively suppress the misleading schemata. This requires extensive accommodation in the style of processing that takes place, as the result of a negative priming effect. To control for this type of processing, the teacher needs to design instruction so as to reduce both the direct and indirect activation of irrelevant information, thereby reducing the need for extensive inhibition. Thus, the aim of this first strategy is to reduce the amount of representational holding and executive inhibitory control involved in the early use of predictive approaches.

Early predictive strategy use requires more representational holding because the number of multiple hypotheses generated are greater at this time. Likewise, the activation of non-relevant schemata is higher, requiring more executive inhibition to suppress these schemata while information is being evaluated and integrated at the WM level. Early predictive strategy use can therefore be characterised by low automaticity and high cognitive load, due to the inhibitory demands being made at this point in the strategy. In terms of instructional encoding, a high degree of instructional ambiguity would naturally exist at this stage of prediction.
From the perspective of cognitive load theory, early predictive strategy use would likely result in a type of redundancy effect, due to the need to integrate overlapping information and ideas relating to similar predictions. Redundancy would also result from the use of identical and similar terms and information that would naturally occur from overlapping solution types. In addition, a split attention effect could also occur, due to various solution types being represented in different presentation modes that are simultaneously available in the early phase of this strategy.

### 7.4.3.1.1 Controlling for early predictive strategy use

It seems apparent that instructional scaffolding needs to be increased during the early phases of prediction strategy use. However, this is a broad, general statement and does not necessarily address the specific inhibitory issues relating to early prediction processing as depicted by the inhibition X cognitive load model of attentional processing. Because this model asserts that controlling for cognitive load, via inhibition, is a necessary condition of effective instructional design, any strategies put forward to account for the misleading aspects of early predictive strategies must involve the use of priming to reduce those elements of early prediction that might contribute to instructional ambiguity. In this respect, the teacher should always seek awareness of how priming will function for the instructional information being presented to the learner, but for early predictive use, the aim of priming should be to specifically reduce the effects of redundancy and split attention as much as possible.

Reducing redundancy means that the teacher has to look for ways of reducing the amount of overlapping and conceptually similar information that may be involved in the early prediction phase. A general organisational principle for this is to minimise the number of predictive factors that have to be considered in the early phase of this strategy. This will help to reduce the number of overlapping schemata the learner has to consider in this phase, and thereby reduce the amount of representational holding involved in the early phase of predictive strategy use. Representational holding contributes significantly to extraneous cognitive load. Thus anything the teacher can do to reduce representational holding will aid the learner in processing information more efficiently at this phase of the strategy.
Priming to reduce redundancy can be obtained by the use of clear visual aides to support direct schematic priming. Thus the use of adjunct clarifying strategies, such as mind maps or flow charts, can be used to activate relevant schemata during this phase of the learning, and thereby limit the amount of initial inhibition occurring due to non-relevant and partially-relevant schemata being activated. In terms of WM capacity, this will decrease demands made upon the learner’s attentional M-space, and thereby increase the efficiency of overall processing during the early prediction phase.

The use of clear schematic priming will also contribute to the student’s ability to categorise different predictive types. Categorisation provides a framework for the learner’s wave of cognitive activation, and thus also lessens the need for schematic suppression. The teacher can further this categorisation benefit, by providing a taxonomy for the most relevant predictive types, and perhaps organise these in terms of complexity or difficulty for the class. This will enable all students to connect their own understanding of the predictive process to the collaborative understanding of the class more easily, and assist them in avoiding much of the distracting or conflicting information that might otherwise arise.

The provision of a predictive taxonomy can be used to further enhance the activation of schemata if the teacher identifies a variety of problem or task types, and then has students self-select the problem or task to work on. Self-selection more naturally connects the learning task to existing knowledge for individual students, in effect priming to reduce the amount of inhibitory demand being made during this initial part of the prediction cycle.

7.4.3.1.2 Summary of controlling for early predictive strategy use

Prediction strategies are primarily concerned with developing problem solving skills for students. However, a major issue relating to the use of this strategy is that the amount of extraneous cognitive load is inconsistent across the strategy use, due to individual differences in student inhibitory ability (“M-capacity” differences), and due to progressive learning effects that narrow attentional focus. According to the inhibition X cognitive load model of attentional processing, instructional scaffolding aimed at reducing the influence of irrelevant or distracting information therefore needs to be specific, and
address problems relating to instructional ambiguity during the early phase of prediction, such as redundancy and split attention. The specific strategies suggested to deal with these issues here are viewed as appropriate to the early phase of predictive strategy use, because they represent the most fundamental finding of the thesis investigation: That individual differences in inhibitory ability moderate the amount of mental effort students experience in relation to learning tasks, and thereby influence task-related selective attentional focus. For this reason, these strategies are put forward as a logical application of the thesis to classroom practice.

### 7.4.3.2 A strategy to embellish facilitating processing in relation to later predictive instructional approaches

In terms of the inhibition X cognitive load model of attentional processing, later predictive strategy use requires less representational holding because the number of multiple hypotheses generated are resolved by this time. Likewise, the activation of non-relevant schemata is lower, requiring less executive inhibition to suppress these schemata while information is being evaluated and integrated at the WM level. Later predictive strategy use can therefore be characterised by higher automaticity and lower cognitive load, due to lessoned inhibitory demands being made at this point in the strategy. In terms of instructional encoding, a lower degree of instructional ambiguity would naturally exist at this stage of prediction. This represents a facilitating processing situation, involving greater germane cognitive load, because there is substantial positive priming inherent to the selection process. Because of this, the selective attentional issues relating to later predictive strategy use are quite different to those of early strategy use, and tend to be more concerned with how to consolidate and expand the overall learning that has taken place across the strategy.

Facilitating situations involve instructional tasks that prime more directly for relevant schemata, and which include cognitive scaffolding for these schemata in the way the information is organised. According to Pascual-Leone (1980; 2000), facilitating situations are aided by additional constructive operators, such as task-relevant content schemata, which activate information according to context and the associative patterns of content-relevant information these schemata contain. Because of their relevant content, such schemata are already primed for processing in relation to the content of the task at
hand, and thus facilitating situations are able to make use of inhibition in a much more
automatised manner. Pascual-Leone purports that this type of processing is more
automatised because the task-relevant schemata are able to be organised via the use of
logical-structural schemata, a type of executive schema that directs activation thresholds,
based on the level of content relevancy for the schemata involved.

This understanding forms a particular and more nuanced view of executive
activation control. From this view, logical-structural schemata are able to determine
hyper-activation from weak activation on the basis of the associative values inherent to the
information itself, thus requiring little if any attentional resources. This could be
considered a primitive, or pre-conscious processing mechanism, whereby logical-
structural schemata are able to boost some schemata into M-space (for selective attention),
whilst holding others in a primed position for possible ongoing processing (in what
Pascual-Leone calls the field of decay), without the need to interrupt executive attention.
Important to the thesis, this selective boosting ability appears to be the key to facilitating
processing, and entails strong, positive priming effects, which are determined by the
learning goals of the situation. Thus, facilitating situations can be supported without
notable use of executive resources by the largely automatised, pre-conscious logical-
structural schemata, which determine how weakly activated schemata are to be primed in
relation to the task at hand.

It seems to the author that this view of facilitation offers a quite elegant
explanation of how constructivism, as an aspect of information processing theory, can be
related to inhibitory ability as an aspect of individual differences. Constructivist principles
are based on the assumption that learners need to personalise learning in terms of
constructing a meaningful relationship between new learning and prior knowledge. The
notion of logical-structural schemata suggests that the degree of instructional encoding for
task-relevant schemata will significantly determine the ability of the logical-structural
mechanism to control the activation thresholds that link prior knowledge to new learning.
This means that the level of inhibitory understanding that informs the teacher’s approach
to instructional design can be expected to form a critical factor in relation to constructivist
learning, as that knowledge will influence the teacher’s use of positive priming in the
encoding of instruction. Importantly, this explanation also underscores the cognitive load
position that a relationship exists between instructional design and extraneous cognitive load.

From the perspective of cognitive load theory, issues relating to later predictive strategy use involve the need to increase information elaboration and learner self-regulation. These become important features of later predictive strategy use because the current educational emphasis upon lifelong learning also requires that teachers and other instructional designers allow the learner to construct the most personalised and meaningful connections possible. Thus, strategies to support this phase of prediction aim to consolidate and embellish the learning achieved across the prediction task for individual learners, in order to extend the automaticity of processing relating to problem solving beyond the limits of the set learning task. Figure 7.4 provides a mind map of the elements relating to elaboration and self-regulation, as determined by the inhibition X cognitive load model of attentional processing.

![Figure 7.4 Mind map of the inhibition X cognitive load relationships relating to later predictive strategy use.](image)

To assist in designing this type of processing at the classroom level, the following strategy is proposed for use at the later phase of prediction. This strategy seeks to increase
the amount of automatised inhibitory control involved in instructional processing, via the organisation of task-relevant content schemata and logical-structural schemata.

7.4.3.2.1 Consolidating and embellishing later predictive strategy use

This strategy is proposed as a means of transferring domain specific knowledge and skills to domain general learning. The strategy aims to extend the facilitating processing relating to the learning of problem solving skills, by connecting the solution type beyond the domain-specific application of the original task, and linking it to more domain-general processes and skills. It is assumed that in this phase of prediction a clear awareness of problem types, solutions types, and prediction outcomes has been integrated by the learner. The processing of task-related information becomes more automatised at this stage of the strategy because the logical-structural schemata relating to information integration are more assimilated, with little accommodation of information required. Because of this, the strategy uses specified fading to reduce instructional support and encourage students to consolidate the domain-specific learning they have achieved, and then transfer this learning into more domain-general knowledge. The steps required to do this are outlined below, but note that these steps are meant to occur in a cyclic manner, allowing the strategy to be applied within an action research framework. It is the ongoing, cyclic application of the strategy that is designed to manage the transfer from specific to general domain use.

In step one of the strategy, students analyse the range of prediction outcomes generated by the entire class, and collaboratively construct a domain-specific taxonomy of solution types. This reduces executive inhibition, because it increases the activation of task-relevant content schemata in relation to solution type. The taxonomy provides for greater automaticity of processing, because it affords an inherent logical-structural schema that is able to prime for more efficient activation of these content schemata. This also provides for a more nuanced activation of the content schemata, due to the way the taxonomy delivers a hierarchically organised range of associative values for these schemata.
In step two of the strategy, students use the taxonomy to complete partial predictions made for a solution type, and generate their own solution outcome for this type. This part of the strategy increases the learner’s use of the logical-structural schemata as a means of controlling the range of associative activation levels involved in the solution types. This also allows the overall goals of the learning situation – the development of domain-specific problem solving skills – to direct the priming of task-relevant schemata, again reducing executive inhibition and representational holding. This part of the strategy is somewhat similar to concept learning, where the student develops an ability to discriminate specific information based on a broad conceptual understanding of how the information relates to a class or category of meaning. Here, however, the concept is represented by the logical-structural schema peculiar to a solution type.

In step three of the strategy, inferences are made about the solution types, based on the logical-structural schemata attached to the taxonomy. The teacher can scaffold for this by having the learner create a visual representation of the solution, and then make inferences about the structure, rationale, and goals of this solution in relation to other solution types. According to Gerjets, Scheiter, and Shuh (2008), such inferences are supported by having the learner make both intra-category comparisons (which map the generalizations for a solution type), and inter-category comparisons (to map specific differences between solution types). The important feature of such comparisons needs to be that they are designed to increase the amount of germane cognitive load, because increases in this type of mental load contribute to automaticity by reinforcing both the content and logical-structural schemata associated with the comparisons. These steps and their relationship to elaboration are shown in figure 7.5. Note that in this strategy depiction, elaboration is driven by the relationship between logical-structural schemata and content schemata, and that the aim of the strategy is to reduce the amount of inhibition and representational holding involved in the generalisation process.
Figure 7.5 An inhibition X cognitive load strategy aimed at consolidating and embellishing later predictive strategy use.

Intra-category comparisons require the learner to use logical-structural schemata knowledge to generalise within a solution type, via the use of analogies that are based on the characteristics of the type. This allows the generation of novel hypotheses in relation to new problems without high demands being made on representational holding or executive inhibition, because the logical-structural schemata prime for analogous activation on the basis of the characteristics of the domain-specific type. Intra-category comparisons are therefore able to afford a means of uncovering the inherent structures for solution types or categories, without making high cognitive load demands on the WM system.

Inter-category comparisons map differences between solution types, yet because the logical-structural schemata control activation for the various content schemata involved, these comparisons are still able to minimise the amount of representational holding and executive inhibition involved in the learning process. This occurs because each solution-type inference, involving the activation of unique content schemata, can be represented in connection with other solution types in a hierarchical manner. Figure 7.6 depicts the overall set of activation relationships involved in this process. Note that this
depiction resembles a propositional network, as discussed in chapter 3 of the thesis. This is relevant to the thesis, because it shows that the overall relationship between logical-structural and content schemata conforms to the principle of spreading activation. In turn, this supports the proposed elaboration strategy by suggesting this strategy represents a fundamental application of information processing theory, wherein the amount of inhibition and cognitive load required to generalise learning may be constrained by priming for the activation itself.

Figure 7.6 Depiction of the hierarchical activation of content schemata by logical-structural schemata.

What is especially relevant to the thesis here, is that when elaboration is understood in this way the instructional designer can adapt their use of priming to suit both domain-specific and domain general learning tasks, whilst continuing to constrain the amount of executive inhibition and representational holding required to do so. Thus, this approach to generalising or transferring learning addresses the issues related to later predictive strategy use (seeking to increase information elaboration and learner self-regulation), by facilitating the transfer of domain-specific learning to domain general application in line with the inhibition X cognitive load model of processing.
7.5 Summary and conclusions for the thesis

Cognitive inhibition is an executive processing mechanism associated with the WM system. It places its own processing load upon the limited resources available to the overall WM system in response to the need to restrain or suppress non-relevant information. WM, as it operates to control the selective attentional processes involved in perception and learning, must balance demands made by inhibition against the demands of short-term memory storage, in order to process instructional information effectively within the capacity constraints of the system. In this respect, cognitive load theory relates inhibition to instructional design by highlighting that, under conditions of processing ambiguity, the WM system is forced to work harder to sequence information in a relevant and meaningful manner.

Based upon this understanding, a fundamental assumption for this thesis has been that the relationship between instructional pedagogy and cognitive learning processes forms a critical juncture in the proper design of instruction. Furthermore, this juncture has been assumed to require an intensely cognitive understanding of the relationship between instruction and learning, because the nexus of this relationship is located in the way the learning process is experienced as mental understanding by the learner. Simply put, the underlying assumption of the thesis is that instructional design shapes learning.

According to the research findings associated with the thesis, one of the primary questions for educators to address in relation to this assumption is how to best connect learning to the wide range of individual differences that characterise an average classroom. Accepting a more integrated model of information processing as the basis for instructional design, one in which the place of inhibition is considered as naturally as that of attentional focus, allows the teacher to use the processing strengths of a student to guide the instructional process more explicitly. According to the current study, adopting this approach will provide a more holistic context for learning and for engaging individual differences more widely, a context in which both the attentional and inhibitory functions of information processing are brought together more fully, in order to encourage deep and lasting learning.
7.6 Limitations and future research

There are various limitations to the study that have been discussed and accounted for, including several concepts relating to cognitive learning theory (metacognition, self-regulated learning, and the construct of learning style), the role of social factors in learning, limitations relating to the analyses of data for the study, the issue of sample size and its effects on statistical power, and the non-orthogonal relationship between inhibition and cognitive load.

Some of these limiting factors have proven non-significant in their impact on the study, for example the role of gender. Yet analyses incorporating other social factors may prove more fruitful for future research in this area, and such research could include data from student factors such as motivation, as this may display important interactions with the information processing functions of interest here, especially cognitive load. In terms of cognitive processing, future research should also examine the impact of more varied information encoding factors, such as the teacher’s use of multi-modal presentations and advance organizers. Analyses that included such additional elements would provide a wider array of possibilities for the research, as well as a broader range of applications for instructional designers.

Limitations for the research associated with this thesis may also stem from the validity of the inter-rater observations. Possible disparities in the observational agreement levels should be addressed in future research by re-examining the operational definitions of the four linguistic elements upon which this data was collected. The research on inter-rater reliability also suggests that future observations concerning the sorts of linguistic distractors used in this study should include sufficient observer training that is specific to the elements being encoded. This was done to some extent in the current study, but the classroom teachers did not receive the same level of observational training as did the research assistant who also gathered this data. This will need to be addressed for future research, in order to more effectively support or disqualify the notion of linguistic encoding as a genuine distractor in classrooms.

Similarly, the scoring of the OSPAN working memory task as performed here may have reduced some of the processing differences between students, especially the specific
levels of accuracy achieved by the sample cohort. A more stringent scoring method might have been to analyse the individual error types more closely. This would allow future research in the area to establish “cleaner” cut-off boundaries, and thereby establish more precise categorical groupings for the students in terms of processing group membership.

An important avenue for future research into the relationship between inhibition and cognitive load will be to devise methods that test inhibition in relation to the intrinsic and essential forms of cognitive load as distinct factors in the overall relationship. The effect sizes for inhibition in relation to cognitive load are quite moderate as recorded here, but this is likely due to the fact that the current study measured cognitive load as a single, global factor. More specific measures of cognitive load may find that the effect size for inhibition varies markedly in relation to the various forms of cognitive load involved in processing. Thus, more nuanced measures of cognitive load, allowing for the contributions of intrinsic and essential cognitive load to be partialled out of subsequent analyses, may well show an increased effect size for inhibition in relation to extrinsic cognitive load.

In this respect, one interesting avenue for future research could involve the area of self-directed learning, which is closely connected to the notion of lifelong learning. The findings for the current study suggest that cognitive inhibition explains at least part of the extrinsic cognitive load experienced in relation to complex learning tasks, and prior cognitive load research suggests that task complexity can be directly related to cognitive load demands. From this perspective research in the area of self-directed learning could utilise a sequence of specific tasks that are ordered from simple to complex in terms of task complexity. Cognitive task analysis could then be used to determine the various levels of cognitive demand being made during each task in terms of the task demands relating to intrinsic, extrinsic, and essential (germane) cognitive load for each task type. This approach would help untangle which types of cognitive load are being activated by specific tasks and by task sub-processes, and it may also be possible to determine the sorts of inhibitory demands (which relate to extrinsic cognitive load) that occur in relation to specific self-directed learning processes, such as self-monitoring and self-evaluation.

Overall, it must be said that research on executive WM function and academic learning remains limited, and requires further investigation. In this respect examining
inhibition in relation to student achievement outcomes, and in relation to the impact of specific instructional approaches on cognitive load, is viewed as beneficial to understanding the pedagogical needs of students. Because of this, linking the current findings to assessment, and using them to develop better intervention strategies for students exhibiting differential levels of inhibitory function, would be yet another logical extension of the present findings for future research. This research would need to initially measure cognitive load in relation to individual assessment tasks, in order to determine the sorts of demands being made upon inhibitory processing during the assessment. Examining classroom distributions for this measure would allow the teacher an indirect inhibitory “snapshot” of the processing demands being made by the assessment. In turn, the teacher’s scaffolding for the assessment could then be more individualised, by grouping the distribution scores and then organising progressive assessment scaffolds for students, differentiated according to the grouped scores.

Probably the most fundamental limitation with respect to the current study is its intentionally narrow scope, which was designed to examine the effects of instructional encoding factors on inhibition and cognitive load. However, in spite of this scope, the analyses presented in this study have demonstrated the existence of a generalised relationship between inhibitory processing and mental effort in relation to learning. The study has also provided evidence that this relationship may affect cognitive processing in a way that influences the learner’s ability to achieve task-related outcomes. Most importantly, the findings suggest that variations in cognitive load can be explained in terms of individual differences for inhibitory function, signifying that inhibition moderates the amount of mental effort experienced during learning.

One thing that seems certain from the present findings is that the inhibition X cognitive load model of processing supports a more holistic application of information processing theory. The current research has shown that this model can be used to both explain and support constructivist instructional strategies by applying individual processing differences to the design of problem-based and inquiry approaches. In this respect the thesis has made an important contribution to the field of instructional design, by providing a cognitive load design principle that shows teachers and other educators how to account for specific cognitive load factors that impact on the learning process.
Additionally, the importance of the current investigation lays in the fact that it has helped to define the types of problems that students with less inhibitory ability experience in relation to mental effort. In this respect it has determined that inhibitory ability responds to instructional encoding in at least a partially systematic way.

Of particular interest is that the study has identified cognitive inhibition as a likely causal mechanism for explaining the influence of extrinsic cognitive load. This finding is important to Cognitive Load Theory, because it allows that theory a means for delineating the causal effects of mental effort at a more empirical level than has been available to the theory prior to the thesis; that is, this finding offers Cognitive Load Theory a way forward in terms of further empirical testing and extrapolation. Thus, while exploration of the role and influence of a wider range of considerations - such as self-awareness, motivation and social factors - might seem desirable, the scope of the present study does seem sufficient to its intent within the context of our current understanding of Cognitive Load Theory. In light of this, further research seeking to expand these findings should focus primarily on convergent measures of cognitive inhibition, specific measures of extraneous cognitive load, and the relationship between these two.

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REFERENCES


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Appendix A:  
Student Cognitive Load Ratings  
(Adapted from Pass & van Merrienboer, 1994. Note that the language used here is meant to reflect an appropriate affinity to the age and social context of the participating students)

Mental Load for the lesson: On the following scale, please rate (by circling the appropriate number), how much mental effort you felt you had to make, to understand the teacher’s instructions and achieve the learning outcomes for this lesson.

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<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
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<tbody>
<tr>
<td>Easy Peasey</td>
<td>A Bit</td>
<td>Moderate Effort</td>
<td>Worked Hard</td>
<td>Too Much!</td>
<td></td>
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</table>

**ITEM RATING** | **WHAT IT MEANS**
---|---
(1) Easy Peasey! | *I could have done this work while talking on the phone or throwing a ball around.*

(2) A Bit | *It took a bit of effort for me to keep up with the lesson, but not much really...Concentration was not difficult to maintain.*

(3 – 4) Moderate Effort  
(3 = low/moderate effort)  
(4 = high/moderate effort) | *I felt I had to work a bit during this lesson, but it wasn’t too difficult...I did have to concentrate though.*

(5 – 6) Worked Hard  
(5 = low/worked hard)  
(6 = high/ worked hard) | *I found this lesson extremely difficult, but managed to keep on top of it by concentrating all the time.*

(7) Too Much! | *This lesson took too much effort...I found it impossible to keep up with the demand. Too hard!*
Appendix B:
Observational rating criteria for the instructional encoding elements
(these elements are assumed to affect incidental processing and representational holding during on-task learning)

The following instructional rating scales are based on the students’ identification of ambiguous instructional activities (as noted in chapter 5 of the thesis), and supported by the notion of “ambiguous” information encoding elements, as described by Harnishfeger (1995) and by Neil, Valdes, and Terry (1995). The application of these elements to classroom instruction is based on the notion that the encoding of instructional information affects the amount of incidental processing and representational holding demands made on the limited capacity WM system (as posited by Mayer & Moreno, 2003).

In terms of how the observed instruction emphasises each of the following elements, each element is to be rated according to the criteria listed below. Note that each element is rated on a Likert-type scale, yet the specific criteria for rating each element varies in terms of the relevant definition for the element, as well as in terms of the way the element is used for instructional purposes.

Teacher # ___             Subject: ________________               Date ___ / ___ / ______

Core learning task for the lesson: _______________________________________
____________________________________________________________________

To the rater: In terms of how the observed instruction emphasises essential information processing, and minimises incidental processing & representational holding, to what degree are each of the following elements present in the observed instruction? Where relevant, you may keep a separate tally for each instance of the element during the observation, along with the amount of time the element is utilised during the lesson.
Element 1 (RELEVANT+): To what degree does the teacher’s instruction clearly discriminate between relevant and irrelevant information in relation to the core learning task of the lesson?

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<tr>
<td></td>
<td>Absent</td>
<td>Low</td>
<td>Moderate</td>
<td>High</td>
<td>Very High</td>
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1 = Teacher presents no core learning information as being relevant and applicable to the core learning task *(no relevant discrimination)*

2 = Teacher presents less than 1/4 of core learning information as being clearly relevant and applicable to the core learning task *(low relevant discrimination)*

3 = Teacher presents between 1/4 and 1/2 of core learning information as being clearly relevant and applicable to the core learning task. *(moderate relevant discrimination)*

4 = Teacher presents between 1/2 and 3/4 of core learning information as being clearly relevant and applicable to the core learning task. *(high relevant discrimination)*

5 = Teacher presents more than 3/4 of core learning information as being clearly relevant and applicable to the core learning task. *(very high relevant discrimination)*
Element 2 (CUE-): When using questioning during lessons, to what degree does the teacher give instructional cues that are semantically distracting in relation to the core learning task of the lesson? (e.g., gives irrelevant background information, refers to core learning task information in a way that provides alternative semantic meaning to the information, uses core learning task information to refer to something other than the core learning task, questions the students about learning task information from a different lesson without noting that the information is not relevant to the current learning task).

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<td></td>
<td>Absent</td>
<td>Low</td>
<td>Moderate</td>
<td>High</td>
<td>Very High</td>
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</table>

1 = Teacher gives no distracting cues during questioning (no cue distraction)
2 = Teacher gives distracting cues for less than 1/4 of questioning (low cue distraction)
3 = Teacher gives distracting cues between 1/4 and 1/2 of questioning (moderate cue distraction)
4 = Teacher gives distracting cues between 1/2 and 3/4 of questioning (high cue distraction)
5 = Teacher gives distracting cues for more than 3/4 of questioning (very high cue distraction)
Element 3 (VALENCE+): To what degree does the teacher define and clarify task-relevant words that possess multiple possible meanings, as used in relation to the core learning task of the lesson? (e.g., provide clear definition and clarification for ambiguous or multi-valent terms that are used in relation to the core learning task of the lesson).

<table>
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<tr>
<th>Scale</th>
<th>Definition</th>
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<tbody>
<tr>
<td>1</td>
<td>Teacher provides no definition or clarification for ambiguous or multi-valent terms used in relation to the core learning task. (no valence clarification)</td>
</tr>
<tr>
<td>2</td>
<td>Teacher provides definition &amp; clarification for ambiguous or multi-valent terms used in relation to the core learning task for less than 1/4 of such terms used. (low valence clarification)</td>
</tr>
<tr>
<td>3</td>
<td>Teacher provides definition &amp; clarification for ambiguous or multi-valent terms used in relation to the core learning task for between 1/4 and 1/2 of such terms used. (moderate valence clarification)</td>
</tr>
<tr>
<td>4</td>
<td>Teacher provides definition &amp; clarification for ambiguous or multi-valent terms used in relation to the core learning task for between 1/2 and 3/4 of such terms used. (high valence clarification)</td>
</tr>
<tr>
<td>5</td>
<td>Teacher provides definition &amp; clarification for ambiguous or multi-valent terms used in relation to the core learning task for more than 3/4 of such terms used. (very high valence clarification)</td>
</tr>
</tbody>
</table>

1 = Teacher provides no definition or clarification for ambiguous or multi-valent terms used in relation to the core learning task.
2 = Teacher provides definition & clarification for ambiguous or multi-valent terms used in relation to the core learning task for less than 1/4 of such terms used.
3 = Teacher provides definition & clarification for ambiguous or multi-valent terms used in relation to the core learning task for between 1/4 and 1/2 of such terms used.
4 = Teacher provides definition & clarification for ambiguous or multi-valent terms used in relation to the core learning task for between 1/2 and 3/4 of such terms used.
5 = Teacher provides definition & clarification for ambiguous or multi-valent terms used in relation to the core learning task for more than 3/4 of such terms used.
**Element 4 (JARGON+):** To what degree does the teacher clearly define jargon words or words that are technically related to a specific area of knowledge, as used in relation to the core learning task of the lesson? (e.g., provide clear definition and application for technical terms or jargon words that are used in relation to the core learning task of the lesson).

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absent</td>
<td>Low</td>
<td>Moderate</td>
<td>High</td>
<td>Very High</td>
</tr>
</tbody>
</table>

1 = Teacher provides no applicable definition for jargon or technical terms used in relation to the core learning task
(no technical definition)

2 = Teacher provides applicable definition for jargon or technical terms used in relation to the core learning task for less than 1/4 of such terms used
(low technical definition)

3 = Teacher provides applicable definition for jargon or technical terms used in relation to the core learning task for between 1/4 and 1/2 of such terms used
(moderate technical definition)

4 = Teacher provides applicable definition for jargon or technical terms used in relation to the core learning task for between 1/2 and 3/4 of such terms used
(high technical definition)

5 = Teacher provides applicable definition for jargon or technical terms used in relation to the core learning task for more than 3/4 of such terms used
(very high technical definition)
Appendix C:
Statistical Modelling of the Hypotheses Using the General Linear Model

The General Linear Model (GLM) represents an approach to statistical reasoning which assumes that significant relationships between variables include both measured values and measurement error as aspects of the overall relationship (Tabachnick & Fidell, 2007). The specific logic of the GLM approach to statistical testing is that it expresses each score on a dependent variable as a linear or additive combination of several independent variables, plus an error value (Baron & Kenny, 1986). In its simplest form, this logic can be expressed as:

\[ Y_j = b_0 + \sum b_iX_{ij} + e_j \]

This logic appears useful in obtaining means for different levels of factors adjusted for other terms in the model ('estimated marginal means') and for tests of pairwise simple effects. It can also be used for regression analysis. Hypotheses can be tested by examining their values and testing whether those values differ from some null (hypothesised) value, or by examining whether a model that constrains some of these values fits the data as well as a model that doesn’t (Tabachnick & Fidell, 2007). The GLM assumes normality, suggesting that as close to 30 participants as possible are needed for each variable of interest in the study. The actual participant sample size for the study was 114 (after attrition). The power analysis \( p[\text{reject a false } H_0] = 1 - \beta \) indicated that this sample size would detect a moderate effect, controlling for type II errors (i.e., the level of assurance that the study findings will not miss a genuine effect from the proposed model during analyses) with a statistical power of 0.56. This analysis, combined with the representative characteristics of the sample (see chpt. 4, section 4.2.1), supports the assumption of normality for the data used in the study.

Below is presented the specific General Linear Model (GLM) for testing of each study hypothesis. Note that the OSPAN variables were used to establish that the student sample was processing information within cognitive-developmental parameters appropriate to their age, and to establish, in line with prior research, that WM tasks
display predictive validity with respect to achievement outcomes. The other variables relate directly to hypothesis testing for the study. Note that the primary focus of the model is upon the relationship between inhibition and mental effort (cognitive load). The following key gives the definitions used to refer to each variable or variable element.

**Key:**

- **OSPAN** = A measure of active WM capacity
  - **Store** (representational holding) = short-term memory scores on the OSPAN
  - **Accuracy** (maths problem-solving ability) = percentage of correctly solved mathematical problems on the OSPAN
- **CI** = Cognitive inhibition scores (Conflict scores, derived from the Flanker Task embedded within the Attentional Networks Test [ANT])
- **CL** = Cognitive load ratings (self-report measure of mental effort, please see Appendix A)
- **RELEVANCE** = Observational ratings for distinctions between relevant and irrelevant information, as made by teachers (T1 – T4) in relation to classroom instruction
- **CUE** = Observational ratings for semantically distracting cues given by teachers (T1 – T4) in relation to classroom instruction
- **VALENCE** = Observational ratings for teachers’ (T1 – T4) clarification of words that possess multiple possible meanings, in relation to classroom instruction
- **JARGON** = Observational ratings for defining jargon words, as made by teachers (T1 – T4) in relation to classroom instruction
- **ACHIEVE** = Individual achievement marks awarded to students by each participating teacher (T1 – T4), with each achievement mark awarded as a percentage of 100 marks possible (achievement marks were awarded to task-relevant learning outcomes for each of the sixteen observed lessons used in the study)

**Conceptual Structure of the GLM Variable Relationships**

**Achievement outcomes =**

\[
\text{CI} \times \text{CL} \times \text{ACHIEVE} \\
\text{CI} \times \text{CL} \times \text{RELEVANT} \times \text{CUE} \times \text{VALENCE} \times \text{JARGON} \times \text{ACHIEVE}
\]

**Instructional Encoding =**

\[
\text{CI} \times \text{RELEVANT} \\
\text{CI} \times \text{CUE} \\
\text{CI} \times \text{VALENCE} \\
\text{CI} \times \text{JARGON} \\
\text{CI} \times \text{RELEVANT} \times \text{CUE} \times \text{VALENCE} \times \text{JARGON} \\
\text{CL} \times \text{RELEVANT} \\
\text{CL} \times \text{CUE} \\
\text{CL} \times \text{VALENCE} \\
\text{CL} \times \text{JARGON} \\
\text{CL} \times \text{RELEVANT} \times \text{CUE} \times \text{VALENCE} \times \text{JARGON}
\]
Cognitive load =
   (for generalised cognitive load)
   CI*CL

   (for instruction-related cognitive load)
   CI*CL*RELEVANT
   CI*CL*CUE
   CI*CL*VALENCE
   CI*CL*JARGON
   CI*CL*RELEVANT*CUE*VALENCE*JARGON

   (for achievement-related cognitive load)
   CL*ACHIEVE*T1
   CL*ACHIEVE*T2
   CL*ACHIEVE*T3
   CL*ACHIEVE*T4
   CL* Ov_ACHIEVE (Overall Achievement)

Inhibition =
   CI scores (Conflict scores, from the embedded [ANT] Flanker Task)

The GLM Variables in relation to each Hypothesis

H₁: That a significant, positive relationship exists between WM function and student achievement outcomes:
   Store*ACHIEVE
   Accuracy*ACHIEVE

H₂: That a significant positive relationship exists between inhibitory ability and cognitive load:
   CI*CL
   CI_Grps[More Able Inhibitors & Less Able Inhibitors] *CL
   CI*Grp CL[Hi Mental Effort & Lo Mental Effort]
   CI_Grps[More Able Inhibitors & Less Able Inhibitors] *Grp CL[Hi Mental Effort & Lo Mental Effort]

H₃: That a significant interaction exists between the students’ inhibitory ability (CI), cognitive load ratings (CL), and the way the teachers encode instruction for relevant vs. irrelevant information:
   CI*CL*RELEVANCE*T1 (Teacher 1)
   CI*CL*RELEVANCE*T2 (Teacher 2)
   CI*CL*RELEVANCE*T3 (Teacher 3)
   CI*CL*RELEVANCE*T4 (Teacher 4)
   CI*CL*RELEVANCE*T1*T2*T3*T4 (Overall Relevance)
**H₄:** That a significant interaction exists between the students’ inhibitory ability (CI), cognitive load ratings (CL), and the way the teachers ask questions in a way that gives irrelevant or distracting semantic cues to the students:

CI*CL*CUE*T₁
CI*CL*CUE*T₂
CI*CL*CUE*T₃
CI*CL*CUE*T₄
CI*CL*CUE*T₁*T₂*T₃*T₄ (Overall Cue)

**H₅:** That a significant interaction exists between the students’ inhibitory ability (CI), cognitive load ratings (CL), and the degree to which the teachers use words with multiple referents available:

CI*CL*VALENCE*T₁
CI*CL*VALENCE*T₂
CI*CL*VALENCE*T₃
CI*CL*VALENCE*T₄
CI*CL*VALENCE*T₁*T₂*T₃*T₄ (Overall Valence)

**H₆:** That a significant interaction exists between the students’ inhibitory ability (CI), cognitive load ratings (CL), and the degree to which the teachers make only weak semantic associations to technical or jargon words:

CI*CL*JARGON*T₁
CI*CL*JARGON*T₂
CI*CL*JARGON*T₃
CI*CL*JARGON*T₄
CI*CL*JARGON*T₁*T₂*T₃*T₄ (Overall Jargon)

**H₇:** That a significant interaction exists between student inhibitory ability (CI), cognitive load (CL), and achievement outcomes (ACHIEVE):

CI*CL*ACHIEVE*T₁
CI*CL*ACHIEVE*T₂
CI*CL*ACHIEVE*T₃
CI*CL*ACHIEVE*T₄
CI*CL*Ov_ACHIEVE (Overall Achievement)
CI_Grps[More Able Inhibitors & Less Able Inhibitors] *Grp_CL[Hi Mental Effort & Lo Mental Effort] *Ov_ACHIEVE
Appendix D: OSPAN & ANT Data Collection Sheets

Student: Study ID:
Sex: Age: yrs, mos
School year: 8 KLA:

**OSPARN Task**

<table>
<thead>
<tr>
<th>Recall (# correct words): Overall M =</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Phase 2</strong></td>
</tr>
<tr>
<td>Level 1:</td>
</tr>
<tr>
<td>Level 2:</td>
</tr>
<tr>
<td>Level 3:</td>
</tr>
<tr>
<td>Level 4:</td>
</tr>
<tr>
<td>Level 5:</td>
</tr>
<tr>
<td>Ph 2 M =</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Accuracy (% correct): Overall M =</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Phase 2</strong></td>
</tr>
<tr>
<td>Level 1:</td>
</tr>
<tr>
<td>Level 2:</td>
</tr>
<tr>
<td>Level 3:</td>
</tr>
<tr>
<td>Level 4:</td>
</tr>
<tr>
<td>Level 5:</td>
</tr>
<tr>
<td>Ph 2 M =</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>RT (ms): Overall M =</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Phase 2</strong></td>
</tr>
<tr>
<td>Level 1:</td>
</tr>
<tr>
<td>Level 2:</td>
</tr>
<tr>
<td>Level 3:</td>
</tr>
<tr>
<td>Level 4:</td>
</tr>
<tr>
<td>Level 5:</td>
</tr>
<tr>
<td>Ph 2 M =</td>
</tr>
</tbody>
</table>
### Student Information

- **Student:** [Name redacted]
- **Study ID:** [ID redacted]
- **Sex:** [Sex redacted]
- **Age:** yrs, mos
- **School year:** 8
- **KLA:** [KLA redacted]

### Attentional Networks Test

<table>
<thead>
<tr>
<th>Measure</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alerting Time (ms)</td>
<td></td>
</tr>
<tr>
<td>Orienting Time (ms)</td>
<td></td>
</tr>
<tr>
<td>Conflict Time (ms)</td>
<td></td>
</tr>
<tr>
<td>Mean RT [for correct trials] (ms)</td>
<td></td>
</tr>
<tr>
<td>Mean Accuracy (%)</td>
<td></td>
</tr>
</tbody>
</table>

### R. T (ms): Overall M =

<table>
<thead>
<tr>
<th>Phase 2</th>
<th>Phase 3</th>
<th>Phase 4</th>
<th>Phase 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1:</td>
<td>Level 1:</td>
<td>Level 1:</td>
<td>Level 1:</td>
</tr>
<tr>
<td>Level 2:</td>
<td>Level 2:</td>
<td>Level 2:</td>
<td>Level 2:</td>
</tr>
<tr>
<td>Level 3:</td>
<td>Level 3:</td>
<td>Level 3:</td>
<td>Level 3:</td>
</tr>
<tr>
<td>Level 4:</td>
<td>Level 4:</td>
<td>Level 4:</td>
<td>Level 4:</td>
</tr>
<tr>
<td>Level 5:</td>
<td>Level 5:</td>
<td>Level 5:</td>
<td>Level 5:</td>
</tr>
<tr>
<td>Ph 2 M =</td>
<td>Ph 3 M =</td>
<td>Ph 4 M =</td>
<td>Ph 5 M =</td>
</tr>
</tbody>
</table>
Appendix E: 
Reliability Analyses for Instructional Encoding

This appendix details the analyses of observational data relating to the classroom instructional elements (RELEVANCE, VALENCE, CUE, and JARGON), as discussed in chapter 6. Because a low inter-rater reliability coefficient occurred for most of these elements, a closer examination of the observational data was deemed appropriate. The discussion below examines each of the instructional encoding elements (as described in Appendix B) in light of its reliability coefficient.

RELEVANCE (.26)

The element RELEVANCE returned a reliability coefficient of .26. A correlation matrix for this element reveals that the encoding for RELEVANCE was similar among the observers for teachers T2, T3, and T4. In contrast, T1 was not observed as encoding RELEVANCE in the same manner. If the scores for T1 are deleted from this analysis, Cronbach’s Alpha rises to .39, suggesting that the low overall reliability coefficient for this element is being noticeably affected by the way T1 was perceived as encoding for RELEVANCE.

Table E.1 Inter-item correlation matrix for RELEVANCE

<table>
<thead>
<tr>
<th></th>
<th>t1_rel</th>
<th>t2_rel</th>
<th>t3_rel</th>
<th>t4_rel</th>
</tr>
</thead>
<tbody>
<tr>
<td>t1_rel</td>
<td>1.000</td>
<td>-.048</td>
<td>-.029</td>
<td>-.003</td>
</tr>
<tr>
<td>t2_rel</td>
<td>-.048</td>
<td>1.000</td>
<td>.315</td>
<td>.322</td>
</tr>
<tr>
<td>t3_rel</td>
<td>-.029</td>
<td>.315</td>
<td>1.000</td>
<td>-.110</td>
</tr>
<tr>
<td>t4_rel</td>
<td>-.003</td>
<td>.322</td>
<td>-.110</td>
<td>1.000</td>
</tr>
</tbody>
</table>

The covariance for this element also shows little consistency between observers for T1, with a negative shared variance again occurring between T1 and the other teachers. The low overall reliability coefficient for RELEVANCE, therefore, seems to reflect something about the way T1 was encoding for this element that did not match the instructional encoding observational criteria (Appendix B) in the same way that the other teachers were seen to encode it.
Table E.2 Inter-item covariance matrix for RELEVANCE

<table>
<thead>
<tr>
<th></th>
<th>t1_rel</th>
<th>t2_rel</th>
<th>t3_rel</th>
<th>t4_rel</th>
</tr>
</thead>
<tbody>
<tr>
<td>t1_rel</td>
<td>.409</td>
<td>-.022</td>
<td>-.011</td>
<td>-.002</td>
</tr>
<tr>
<td>t2_rel</td>
<td>-.022</td>
<td>.532</td>
<td>.131</td>
<td>.191</td>
</tr>
<tr>
<td>t3_rel</td>
<td>-.011</td>
<td>.131</td>
<td>.327</td>
<td>-.051</td>
</tr>
<tr>
<td>t4_rel</td>
<td>-.002</td>
<td>.191</td>
<td>-.051</td>
<td>.666</td>
</tr>
</tbody>
</table>

CUE (.52)

Although not strong, at .52 the reliability coefficient for CUE was acceptable. The correlation matrix for this element shows that most similarities were recorded between T3 and T4, with some overlap also occurring between T4 in relation to both T1 and T2. As for RELEVANCE, the lowest overall similarities were recorded between T1 and the other teachers. Cronbach’s Alpha for CUE if the scores for T1 were deleted = .57.

Table E.3 Inter-item correlation matrix for CUE

<table>
<thead>
<tr>
<th></th>
<th>t1_cue</th>
<th>t2_cue</th>
<th>t3_cue</th>
<th>t4_cue</th>
</tr>
</thead>
<tbody>
<tr>
<td>t1_cue</td>
<td>1.000</td>
<td>.097</td>
<td>.059</td>
<td>.229</td>
</tr>
<tr>
<td>t2_cue</td>
<td>.097</td>
<td>1.000</td>
<td>.152</td>
<td>.283</td>
</tr>
<tr>
<td>t3_cue</td>
<td>.059</td>
<td>.152</td>
<td>1.000</td>
<td>.517</td>
</tr>
<tr>
<td>t4_cue</td>
<td>.229</td>
<td>.283</td>
<td>.517</td>
<td>1.000</td>
</tr>
</tbody>
</table>

As shown in Table E.4, covariance analysis for CUE shows that a small amount of shared error exists for T3 in relation to T4. Otherwise, the lack of shared variance for this element again highlights that encoding differences between the teachers are a characteristic of these observations.

Table E.4 Inter-item covariance matrix for CUE

<table>
<thead>
<tr>
<th></th>
<th>t1_cue</th>
<th>t2_cue</th>
<th>t3_cue</th>
<th>t4_cue</th>
</tr>
</thead>
<tbody>
<tr>
<td>t1_cue</td>
<td>.397</td>
<td>.031</td>
<td>.027</td>
<td>.075</td>
</tr>
<tr>
<td>t2_cue</td>
<td>.031</td>
<td>.264</td>
<td>.057</td>
<td>.076</td>
</tr>
<tr>
<td>t3_cue</td>
<td>.027</td>
<td>.057</td>
<td>.537</td>
<td>.198</td>
</tr>
<tr>
<td>t4_cue</td>
<td>.075</td>
<td>.076</td>
<td>.198</td>
<td>.272</td>
</tr>
</tbody>
</table>
VALENCE (.18)

The overall reliability coefficient of .18 for VALENCE derives largely from the very different pattern of VALENCE encoding that was observed for T1 in relation to the other teachers. The correlation matrix for VALENCE suggests that T1 was observed to have encoded for this element in a manner opposite to T2 and T3, and with virtually no similarity to T4. T4, on the other hand, seemed to encode in a manner similar to both T2 and T3. Cronbach’s Alpha for VALENCE if the scores for T1 were deleted = .57.

Table E.5 Inter-item correlation matrix for VALENCE

<table>
<thead>
<tr>
<th></th>
<th>t1_val</th>
<th>t2_val</th>
<th>t3_val</th>
<th>t4_val</th>
</tr>
</thead>
<tbody>
<tr>
<td>t1_val</td>
<td>1.000</td>
<td>-.353</td>
<td>-.362</td>
<td>.008</td>
</tr>
<tr>
<td>t2_val</td>
<td>-.353</td>
<td>1.000</td>
<td>.103</td>
<td>.416</td>
</tr>
<tr>
<td>t3_val</td>
<td>-.362</td>
<td>.103</td>
<td>1.000</td>
<td>.348</td>
</tr>
<tr>
<td>t4_val</td>
<td>.008</td>
<td>.416</td>
<td>.348</td>
<td>1.000</td>
</tr>
</tbody>
</table>

In terms of covariance, it appears that T4 has some minor shared error variance with T2 and T3. Yet, overall, covariance remains quite low among all the teachers for VALENCE.

Table E.6 Inter-item covariance matrix for VALENCE

<table>
<thead>
<tr>
<th></th>
<th>t1_val</th>
<th>t2_val</th>
<th>t3_val</th>
<th>t4_val</th>
</tr>
</thead>
<tbody>
<tr>
<td>t1_val</td>
<td>.379</td>
<td>-.160</td>
<td>-.133</td>
<td>.004</td>
</tr>
<tr>
<td>t2_val</td>
<td>-.160</td>
<td>.541</td>
<td>.045</td>
<td>.231</td>
</tr>
<tr>
<td>t3_val</td>
<td>-.133</td>
<td>.045</td>
<td>.356</td>
<td>.157</td>
</tr>
<tr>
<td>t4_val</td>
<td>.004</td>
<td>.231</td>
<td>.157</td>
<td>.570</td>
</tr>
</tbody>
</table>

JARGON (.42)

The inter-item correlation matrix for JARGON shows that T1 was observed as encoding the element in a manner opposite to that of T4, and with only negligible similarity to T2 and T3. In contrast to this, T3 was observed as having moderate similarity in the way she encoded for JARGON to that of both T2 and T4. Cronbach’s Alpha if the scores for T1 are removed from the analysis of JARGON = .50.
Table E.7 Inter-item correlation matrix for JARGON

<table>
<thead>
<tr>
<th></th>
<th>t1_jar</th>
<th>t2_jar</th>
<th>t3_jar</th>
<th>t4_jar</th>
</tr>
</thead>
<tbody>
<tr>
<td>t1_jar</td>
<td>1.000</td>
<td>.195</td>
<td>.138</td>
<td>-.158</td>
</tr>
<tr>
<td>t2_jar</td>
<td>.195</td>
<td>1.000</td>
<td>.360</td>
<td>.102</td>
</tr>
<tr>
<td>t3_jar</td>
<td>.138</td>
<td>.360</td>
<td>1.000</td>
<td>.488</td>
</tr>
<tr>
<td>t4_jar</td>
<td>-.158</td>
<td>.102</td>
<td>.488</td>
<td>1.000</td>
</tr>
</tbody>
</table>

A look at the covariance matrix for JARGON reveals no significant shared error variance for the encoding of JARGON observed between the teachers.

Table E.8 Inter-item covariance matrix for JARGON

<table>
<thead>
<tr>
<th></th>
<th>t1_jar</th>
<th>t2_jar</th>
<th>t3_jar</th>
<th>t4_jar</th>
</tr>
</thead>
<tbody>
<tr>
<td>t1_jar</td>
<td>.407</td>
<td>.108</td>
<td>.041</td>
<td>-.081</td>
</tr>
<tr>
<td>t2_jar</td>
<td>.108</td>
<td>.752</td>
<td>.146</td>
<td>.071</td>
</tr>
<tr>
<td>t3_jar</td>
<td>.041</td>
<td>.146</td>
<td>.220</td>
<td>.185</td>
</tr>
<tr>
<td>t4_jar</td>
<td>-.081</td>
<td>.071</td>
<td>.185</td>
<td>.654</td>
</tr>
</tbody>
</table>

Taken together, the correlation and covariance data for these elements show that RELEVANCE and VALENCE were observed as being encoded less reliably within the study, while both CUE and JARGON were observed as being encoded more reliably. Summarising this data, there appear to be similarities between teachers T2, T3, and T4 for RELEVANCE, VALENCE, and JARGON. There also appears to be substantial similarity in the encoding for CUE between teachers T3 and T4, with some similarity also occurring for T4 in relation to T1 and T2. The main point of difference across all these observations appears to be teacher T1, who is consistently viewed as encoding in a manner opposite to the other teachers. T1 thus seems to be marked as a distinct instructional influence within the study, and this appears to have affected the overall reliability estimates for these observations.
Appendix F:
Overview of the OSPAN

The chief measure of working memory (WM) function for this study was the OSPAN, a
measure of complex, or overall WM function that has been widely used to measure processing
ability concurrent with short-term memory store. The OSPAN has been generally used to
provide an overall indication of WM capacity, provided as a composite measure of processing
accuracy, response time, and memory store. Because the current study used the OSPAN results
to indicate accuracy, RT, and memory store as separate functions of the WM system, an
overview of how this measure was structured and used within the study is presented here.

During the experimental phase of this study participants (Ps) were individually
administered a complex measure of WM capacity, the operation-word span task (OSPAN ~
Turner & Engle, 1989). The OSPAN builds upon the work of Daneman and Carpenter (1980),
who utilised concurrent processing to support a multi-component model of WM, and, according
to Turner and Engle (1989, p. 134), demonstrates high reliability estimates for internal
consistency (.89 .93, Cronbach’s alpha). This test entails two distinct processing tasks, a
secondary task that involves mentally solving arithmetic operations and making a value
judgment as to whether the operations are correct or wrong, and a primary task that involves
memorising single words that appear with the operations and are later recalled at set intervals.
Thus the OSPAN is a composite WM assessment, and is assumed to measure comprehensive or
overall WM capacity, that is, both executive functions as well as short-term memory store.

The OSPAN format for this study consists of five distinct phases: An orientation phase
(phase 1), phase 2 (a baseline phase), phase 3, phase 4, and phase 5. The orientation phase
consists of 12 mathematical equations only (no words to remember), and elicits an average
math’s problem-solving response time for each Ps, which can later be used to help determine
whether they are using rote memory to remember the words of the task. Each phase other than
orientation consists of 60 sets of mathematical problems that require the Ps to respond to in
terms of “true” or “false”, plus a single word to be held in short-term memory for subsequent
recall.

OSPAN testing procedure

During the orientation phase individual Ps are seated before a computer and instructed
to focus their attention on the monitor screen. Upon hitting the request button, a sequence of 12
arithmetic operations are displayed sequentially. Each operation (i.e., \(4x7 - 7 = 21\)) remains visible until a Ps responds with either 'True' or 'False' as a value judgment concerning the operation, or until a maximum of 10 seconds - after which the item is considered “timed-out” and a response-time value of 10 seconds awarded.

Following orientation, the program pauses and instructions relating to phase two of the test are displayed on the screen. At this point Ps are instructed that a word to be remembered and later recalled would now be displayed with each arithmetic operation. The request button then initiates phase 2 (baseline) for the WM test (baseline information was used to determine whether each Ps was processing overall task information at developmentally appropriate levels). The test progresses through five phases, with each phase composed of five operation-word set levels (the levels get progressively longer within each phase of the task). A pause occurs at the end of each level for word recall, which is given verbally. The experimenter records the number of correct recall words against a sheet containing the correct list for each set, level and phase of the test. At the end of every level the computer program pauses and the Ps is instructed to hit “Enter” plus “L” (level) on the keyboard to progress to the next level. This continues through level six of each phase, at which “Enter” plus “P” (phase) is struck to begin the next phase. The test proceeds in this manner through to phase five. At the end of phase five, Ps are given a debriefing prompt consisting of a question asking them how they thought they had performed on the test.

**OSPAN Content**

The content of the OSPAN follows, listed by phase of the test:

### Phase 1 (Orientation)

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<tr>
<td>3 - (8/4) = 5</td>
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<tr>
<td>(6x7) - 5 = 37</td>
<td>T</td>
<td></td>
</tr>
<tr>
<td>(4/2) + 5 = 9</td>
<td>F</td>
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</tr>
<tr>
<td>(9x3) + 9 = 36</td>
<td>T</td>
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<tr>
<td>(8/2) + 8 = 10</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>(9/3) - 2 = 6</td>
<td>F</td>
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</tr>
<tr>
<td>(4x7) - 7 = 21</td>
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<tr>
<td>7 - (8/2) = 3</td>
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<td>(6/3) + 5 = 9</td>
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<td>7 + (8x7) = 63</td>
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<td>T</td>
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<td></td>
<td>(6/3) - 2 = 1</td>
<td>Bull</td>
<td>F</td>
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<td>(Recall)</td>
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<td></td>
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<td>(6/3) + 6 = 8</td>
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<td>T</td>
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<td>(3x7) - 8 = 13</td>
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<td>(7x5) + 6 = 43</td>
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</table>
(3x7) + 4 = 25  Lips   T  
(7x7) + 4 = 53  Beat   T  
(3x5) - 6 = 11  Plate  F  
(7x7) - 4 = 45  Board  T  
9 + (6/3) = 14  Mare  F  
9 + (2x8) = 25  Bear  T  
(7x8) + 5 = 61  Cross  T  
5 - (6/3) = 1  Swing  F  
9 + (8/2) = 13  Pine  T  
(7x8) - 5 = 48  Coat  F  
9 - (6/3) = 7  Teat  T  
(7x7) + 7 = 54  Soap  F  
(6/3) + 6 = 9  Freight  F  

(Recall)

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<td>Fact</td>
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### Phase 4

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<td>T</td>
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</table>

### (Recall)

<table>
<thead>
<tr>
<th>Level</th>
<th>EQN</th>
<th>Word</th>
<th>Truth Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.2</td>
<td>(6/3) + 6 = 8</td>
<td>Won</td>
<td>T</td>
</tr>
<tr>
<td></td>
<td>4 + (3x9) = 24</td>
<td>Strive</td>
<td>F</td>
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<tr>
<td></td>
<td>(6/3) - 2 = 0</td>
<td>Brave</td>
<td>T</td>
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<tr>
<td></td>
<td>3 + (6x8) = 43</td>
<td>Coach</td>
<td>F</td>
</tr>
<tr>
<td></td>
<td>4 - (8/2) = 2</td>
<td>Have</td>
<td>F</td>
</tr>
<tr>
<td></td>
<td>5 + (8/4) = 7</td>
<td>Itch</td>
<td>T</td>
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<tr>
<td></td>
<td>(8x7) - 7 = 49</td>
<td>Fact</td>
<td>T</td>
</tr>
<tr>
<td></td>
<td>(6x7) - 6 = 36</td>
<td>Spleen</td>
<td>T</td>
</tr>
<tr>
<td></td>
<td>4 - (9/3) = 7</td>
<td>Knife</td>
<td>F</td>
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</tbody>
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### (Recall)

<table>
<thead>
<tr>
<th>Level</th>
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<th>Word</th>
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<tbody>
<tr>
<td>4.3</td>
<td>(3x5) + 6 = 21</td>
<td>Score</td>
<td>T</td>
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<tr>
<td></td>
<td>(7x7) - 4 = 43</td>
<td>Slide</td>
<td>F</td>
</tr>
<tr>
<td></td>
<td>(9x6) - 6 = 48</td>
<td>Cow</td>
<td>T</td>
</tr>
<tr>
<td></td>
<td>(9/3) - 2 = 1</td>
<td>Sex</td>
<td>T</td>
</tr>
<tr>
<td></td>
<td>(7x5) - 6 = 29</td>
<td>Brown</td>
<td>T</td>
</tr>
<tr>
<td></td>
<td>(3x5) - 9 = 4</td>
<td>Seat</td>
<td>F</td>
</tr>
<tr>
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<td>(7x7) + 7 = 54</td>
<td>Soap</td>
<td>F</td>
</tr>
<tr>
<td></td>
<td>(6/3) + 6 = 9</td>
<td>Freight</td>
<td>F</td>
</tr>
<tr>
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<td>(3/1) - 1 = 1</td>
<td>Bliss</td>
<td>F</td>
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</tbody>
</table>
9 - (2x4) = 3          Neck F
5 - (6/3) = 1          Swing F
9 + (8/2) = 13         Pine T

(Recall)

4.4 (4x7) - 7 = 25      Felt F
(8x7) - 4 = 48         Back F
5 - (6/3) = 3          Lid T
(3x7) - 4 = 14         Line F
(9x7) + 4 = 63         Dog F
(6x7) + 5 = 45         Throw F
6 + (6/3) = 8          Bird T
9 - (4/2) = 7          Purse T
(4/2) + 6 = 8          Cord T
7 + (8x7) = 66         Gloat F
5 + (9/3) = 11         Chalk F
(8x7) + 7 = 63         Light T
(6/2) + 9 = 11         Bean F
(3x7) + 4 = 28         Screen F
5 - (8/4) = 1          Cloud F

(Recall)

4.5 9 - (8/2) = 5       Pant T
5 + (9/3) = 8          Stall T
(9x6) - 7 = 47         Mend T
4 + (7x8) = 60         Slim T
6 - (6/3) = 2          Clean F
(7x5) - 6 = 27         House F
(3x7) + 8 = 29         Cold T
(9/3) + 9 = 6          Shelf F
(9x7) - 4 = 57         Chop F
5 + (8/4) = 13         Hoard F
4 - (6/2) = 1          Birch T
(6x7) + 6 = 48         Done T
4 - (8/2) = 2          Bark F
5 + (8/4) = 7          Phone T
(6x7) - 6 = 36         Spleen T
(6/3) - 2 = 0          Fun T
5 + (8x4) = 33         Hare F
(9x7) - 7 = 56         Quest T

(Recall)

**Phase 5**

<table>
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<th>Level</th>
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<th>Truth Value</th>
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<tr>
<td>5.1</td>
<td>(9x7) - 4 = 59</td>
<td>Boy</td>
<td>T</td>
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<tr>
<td></td>
<td>(7x5) + 6 = 41</td>
<td>Blouse</td>
<td>T</td>
</tr>
<tr>
<td></td>
<td>(7x8) - 5 = 51</td>
<td>Bean</td>
<td>T</td>
</tr>
<tr>
<td></td>
<td>(3x7) - 8 = 16</td>
<td>Juice</td>
<td>F</td>
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<tr>
<td></td>
<td>9 + (2x4) = 17</td>
<td>Flew</td>
<td>T</td>
</tr>
<tr>
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<td>5 + (4x7) = 33</td>
<td>Right</td>
<td>(Recall)</td>
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<td>5.2</td>
<td>5 + (4x7) = 29</td>
<td>Round</td>
<td>F</td>
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<td></td>
<td>6 + (8/4) = 12</td>
<td>Bridge</td>
<td>F</td>
</tr>
<tr>
<td></td>
<td>9 - (6/3) = 5</td>
<td>Hinge</td>
<td>F</td>
</tr>
<tr>
<td></td>
<td>7 - (9/3) = 3</td>
<td>Pause</td>
<td>F</td>
</tr>
<tr>
<td></td>
<td>6 - (6/3) = 4</td>
<td>Rug</td>
<td>T</td>
</tr>
<tr>
<td></td>
<td>(9x7) - 7 = 56</td>
<td>Quest</td>
<td>T</td>
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</table>
7 - (7/7) = 0    Shred    F
3 + (6x8) = 51  Pawn    T
4 + (3x9) = 31  Night    T
(Recall)

| 5.3  | 9 - (2x4) = 1  | Brand    | T |
|      | 4 + (9/3) = 11 | Armed    | F |
|      | 6 + (6/3) = 11 | Ring     | F |
|      | (7x7) - 7 = 42 | Wheat    | T |
|      | 5 + (8x4) = 33 | Hare     | F |
|      | 7 + (8/2) = 23 | Ewe      | F |
|      | 9 + (8/2) = 16 | Grass    | F |
|      | (7x7) - 7 = 38 | Too      | F |
|      | (3x5) + 9 = 24 | Road     | T |
|      | 7 + (3x7) = 28 | Delve    | T |
|      | 4 - (8/2) = 2  | Bark     | F |
|      | 5 + (8/4) = 7  | Phone    | T |
|      | (Recall)       |          |   |

| 5.4  | (3x5) - 9 = 6  | Heat     | T |
|      | (9x7) - 4 = 57 | Chop     | F |
|      | 5 + (8/4) = 13 | Hoard    | F |
|      | 5 - (9/3) = 2  | Book     | T |
|      | 9 + (2x8) = 27 | Whale    | F |
|      | (3x5) - 6 = 9  | Bath     | T |
|      | 6 - (8/4) = 2  | Hat      | F |
|      | 4 + (5x8) = 44 | Gay      | T |
|      | 7 + (8/2) = 11 | Fright   | T |
|      | 4 + (7x8) = 60 | Slim     | T |
|      | 6 - (6/3) = 2  | Clean    | F |
|      | 9 + (2x4) = 23 | Couch    | F |
|      | 4 + (5x8) = 49 | Chewed   | F |
|      | 7 + (3x9) = 43 | Lock     | F |
|      | 5 - (8/4) = 1  | Cloud    | F |
|      | (Recall)       |          |   |

| 5.5  | 9 - (8/2) = 2  | Tyre     | F |
|      | 5 - (8/4) = 3  | Whine    | T |
|      | 7 + (8x7) = 66 | Gloat    | F |
|      | 5 + (9/3) = 11 | Chalk    | F |
|      | 5 + (8x4) = 37 | Cheek    | T |
|      | 6 + (8/4) = 8  | Fork     | T |
|      | 9 - (4/2) = 5  | Trench   | F |
|      | 4 - (6/2) = 3  | Shrew    | F |
|      | 3 + (6/3) = 5  | Box      | T |
|      | (8/4) + 8 = 10 | Prop     | T |
|      | (9x7) + 4 = 63 | Dog      | F |
|      | (6x7) + 5 = 45 | Throw    | F |
|      | (3/1) - 1 = 1  | Bliss     | F |
|      | 6 - (8/4) = 4  | Crack    | T |
|      | 7 - (8/2) = 9  | Knave    | F |
|      | 9 + (4/2) = 11 | Roof     | T |
|      | (4/2) + 6 = 8  | Cord     | T |
|      | 3 + (6/3) = 5  | Tack     | T |
|      | (Recall)       |          |   |

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