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Applying Cognitive Psychology Principles to Education and Training

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For an overview of Cognitive Load Theory & Instructional Design issues please see:
http://www.arts.unsw.edu.au/education/clt.html

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Human Cognition and Cognitive Load Theory

Dr Paul Chandler

This paper examines the cognitive processes involved in learning and understanding instructions. By identifying the cognitive mechanisms involved in assimilating instructional and training materials, we may be in a position to decide both when instructional design is most important and how educational materials should be presented. I will begin the paper by discussing the cognitive structures and processes that govern our theorising.

Core Cognitive Processes Involved in Learning and Understanding

For any information to be learned, it first must be processed through working memory. Working memory is where current mental activity takes place and is a cognitive structure that is very limited in both capacity and duration (Simon, 1974). Only a limited number of elements of information can be held in working memory (Miller, 1956) and even less if these elements need to combined or processed concurrently (Halford, Maybery & Bain, 1986; Sweller & Chandler, 1994). If instructional material is presented in a way that prevents working memory from successfully processing it, then learning and understanding will be hindered. In fact, recent research indicates that limited working memory may be the single most critical factor that needs to be considered when designing education instructions (Chandler & Sweller, 1991; 1992; 1996; Jeung, Chandler & Sweller, 1997; Paas, 1992; Paas & Van Merrienboer, 1994; Sweller, Chandler, Tierney & Cooper, 1990; Tindall, Chandler & Sweller, 1997).

Information that is successfully processed through working memory is held in long term memory. In contrast to working memory, long term memory is immeasurably large with no known limits (Newell & Simon, 1972). Ironically, an awareness of the size and importance of this cognitive structure, originally came from research into problem solving expertise, an area initially not thought to be directly related to long term memory. The pioneering work by

DeGroot in the 1940's (see DeGroot, 1966), showed that the major difference between expert and novice chess players was not superior search moves or larger working memories, but instead, the experts enormous store of real game configurations held in long term memory (also see Chase & Simon, 1973). Chess experts can recognise most of the configurations encountered in a typical game by drawing on their huge bank of stored board configurations and consequently are aware of the best move associated with each particular configuration. Replication of the research by DeGoot, in a range of problem solving areas (e.g., Egan & Shwartz, 1979; Jeffries, Turner, Polson & Atwood, 1981; Sweller & Cooper, 1985), indicates that long term memory plays a crucial role in higher intellectual behaviour.

Cognitive scientists have known for some time that long term memory is highly structured and organised. The knowledge structures that form long term memory are often referred to as schemas (Chi, Glaser & Rees, 1982; Gick & Holyoak, 1983). Schemas can be defined as general knowledge structures that encapsulate numerous elements of information into a single element and organised into a manner in which it can be widely used. For example, we have a schema for the letter *a* which allows immediate recognition of it, irrespective of the countless ways it can be printed or handwritten. Our schema allows us to ignore the infinite variations of the letter and any other irrelevant information. For a child, not yet familiar with the alphabet, the letter *a* cannot be treated as a single element and instead is likely to be treated as multiple unrelated marks on the page. Research indicates that problem solving expertise is heavily dependent on the presence of domain specific schemas (Chi et al., 1982; Larkin, Simon & Simon, 1980). For example, in the area of science, Chi et al., (1982) found that experts categorised physics problems on the basis on how they could be solved while novices not possessing the appropriate schemas categorised the same problems on surface structures such as similar shapes. A categorisation based on solution mode is obviously far more useful for effective problem solving than a grouping based on structural similarities. Thus, research suggests that intellectual expertise is heavily reliant on the acquisition and formation of schemas in long term memory. In short, schema acquisition is a critical factor in learning.

Another important factor in learning, is the transfer of schematic knowledge from controlled to automatic processing (Schneider & Shriffin, 1977; Shriffin & Schneider, 1977). Most learning tasks initially require considerable conscious effort and consequently make heavy demands on working memory. For example, a child might have a schema for the word*cat* , but might require extensive conscious thought to recognise and classify it. After time and extensive practice recognition of the word will become automatic. Automatic processing is important to learning, for as is the case with schema acquisition, it reduces the burden on working memory and allows cognitive resources to be directed to other important activities. For example, a child is more likely to extract meaning from a story once they have the schemas for all the appropriate words automatised. Research indicates that automatic processing is essential to problem solving transfer and using learned knowledge in new contexts (Cooper & Sweller, 1987; Kotovsky, Hayes & Simon, 1985). In summary, schema acquisition and automatic processing are two of the most important factors in learning and understanding. Automated schemas not only provide the structure for long term memory, but also allows us to effortlessly process information through limited working memory.

Sources of cognitive load that affect learning and understanding

Cognitive load theory (Sweller, 1988; 1993; 1994; Sweller & Chandler, 1994; also see our website, Cooper, 1998) provides the theoretical framework for the experiments of this paper. It accepts the above cognitive model as containing the basic mental structures and processes involved in learning. The theory assumes that all learning occurs through a very limited working memory and an unlimited long term memory which is structured into hierarchically ordered automated schemas. Cognitive load theory asserts that when instructional information is presented to students, the amount of mental load placed on working memory will be the critical factor in determining how effective learning has been. If the level of mental load exceeds the limits of working memory, then learning will be hindered.

In examining the factors involved in learning instructions, Sweller and Chandler (1994) identify two separate sources of cognitive load. First, the intrinsic cognitive load is generated by the intellectual complexity of the instructions (e..g. the difficulty involved in constructing a particular molecule model). Second, the extraneous cognitive load is determined by how the information is presented (e.g., text format or diagrams). Intrinsic and extraneous load together contribute to the total cognitive load involved in a learning task. We will first discuss the factors that affect intrinsic cognitive load.

Intrinsic cognitive load - Nature of the instructional material

Sweller (1993) and Sweller and Chandler (1994) assert that the degree to which elements interact determines intrinsic cognitive load. An element is any information to be learned that is held as a single item in working memory. Some information presented to students involves learning elements that can be processed sequentially without reference to other elements. Since learning elements do not interact, the information is said to be low in element interactivity and therefore low in intrinsic load. Consider the following example. When learning a second language, say French, the translation of the word "cat" can be learned without needing to know the translation for "dog". For this task, intrinsic cognitive load is low because there is little if any interaction between learning elements. It is important to note that while elements can be processed one at a time, and therefore will be low in intrinsic load, they may be difficult to learn if there are many elements to process. In contrast, other instructions require students to process elements simultaneously rather than sequentially. For example, forming sentences involves learning the grammatical, syntactical and semantic characteristics of the second language. This is a task that is relatively high in element interactivity as the elements involved cannot be separated into autonomous elements. For example, for a person learning English the sentence "The cat sat on the mat" can only be understood if individual learning elements (words) and their relations are processed simultaneously. Instructional information such as this example requires learners to concurrently process learning elements, therefore, they are relatively high in element interactivity and consequently high in intrinsic load.

Extraneous Load - Organisation of the instructional material

While intrinsic load is generated by the intellectual complexity of the learning material, extraneous load is determined solely by how the instructions are formatted. Instructional material can be presented in a variety of ways and each method of presentation varies in extraneous load. Instructional formats that involve a low extraneous load or attempt to reduce extraneous load as much as possible are obviously more beneficial to learning than instructions that impose an unnecessarily high extraneous load.

One common example of inefficient instruction is when teaching materials present mutually referring information separately (eg. a diagram and text). Research has indicated that if both sources of information are necessary for understanding, then the process of mentally integrating related information will impose a heavy extraneous cognitive load on working memory and interfere with learning. The mental load is extraneous as it is unrelated to learning and is imposed purely by the instructional format. Mental integration, the process of searching and matching related entities must be done *before* learning can commence. Sweller, Chandler, Tierney and Cooper (1990) and Chandler and Sweller (1991; 1992) found that if related information is physically integrated then search is reduced and learning enhanced. They labelled this phenomena the split-attention effect and demonstrated the advantages of physically integrated teaching packages in a range of instructional areas in laboratory and field studies in both educational and industrial settings.

However, recent research suggests that the relationship between cognitive load and learning is more complex. As discussed earlier, the total cognitive load imposed on a students' working memory is a function of both intrinsic and extraneous load. If instructions impose high intrinsic load generated by a high level of element interactivity and the level of extraneous load is high because of poor instructional design, then the total load on working memory is likely to be excessive and learning will be hampered. However, if there is little or no interactivity between learning elements, then the intrinsic load may not be high enough for the extraneous load caused by the instructional design to be of any consequence.

Research in a range of educational areas indicates the format of instructions is only a critical factor for learning when intrinsic load is high. Specifically, when intrinsic load was high then instructional designs that aimed to reduce extraneous load were shown to be highly effective learning tools (see Sweller, 1993 for a summary of instructional designs that reduce extraneous load). Under conditions when intrinsic load was low the instructional format was of little consequence (Cerpa, Chandler & Sweller, 1996; Chandler & Sweller, 1996; Marcus, Cooper & Sweller, 1996; Sweller & Chandler, 1994; Tindall, Chandler & Sweller, 1997).

In summary, this section of the paper has addressed the major aspects of cognitive load theory. We have asserted that schema acquisition and automation are two major learning mechanisms which allow us to essentially by-pass limited working memory and emphasis our extensive long term memory. Research has indicated that teaching materials designed to lessen extraneous mental load by reducing search and eliminating processing of unnecessary information facilitate the learning process. Further research examining the intrinsic cognitive load associated with learning instructional materials indicates that instructional interventions are most effective in areas where the material involves a substantial intellectual component generated by a high degree of element interactivity. In the following sections we will report several studies examining the conditions under which audio/visual instruction is beneficial; an instruction condition that uses rote learning to aid in gaining meaningful understanding and finally, the improvement of cognitive performance through the use of mental rehearsal.

Optimising Multi Media Instruction

Dr Sharon Tindall - Ford

Cognitive research has indicated that many traditional approaches to teaching and training are inadequate as they fail to take into account learners cognitive architecture and in particular the limited processing capacity of working memory. Contemporary research suggests that working memory is not a simple structure but composed of multiple channels. These channels include a visual system for dealing with visual images and an auditory system for processing verbal information. The two systems appear to process their different types of information independently with little interference (Penney, 1989; Baddeley, 1992). A proposed method to increase the effective capacity of working memory is to present information in a dual (e.g. visual and auditory) rather than singular mode of presentation. For example, presenting a diagram visually with corresponding text in an audio form rather than the traditional visual mode. A series of papers (Mousavi, Low & Sweller, 1995; Tindall- Ford, Chandler & Sweller, 1997, Jeung, Chandler & Sweller, 1997; Kalyuga, Chandler & Sweller, 1998) have examined this 'modality' effect from a cognitive load perspective. This paper summarises their findings.

As discussed previously in Dr. Chandler's paper, research by Chandler & Sweller (1991, 1992, 1996) and Sweller & Chandler (1994) has indicated that conventional instructions which involve "split source" formats (e.g., separate diagram and text) are ineffective learning vehicles as they involve extensive search, impose a heavy extraneous cognitive load on working memory and therefore hinder learning. Research has demonstrated that physically integrated instructional formats where text is physically integrated with related identities on a diagram enhance understanding by reducing the on going search process. Providing instructional material in a dual medium, for example viewing a diagram while listening to explanatory textual information, may be a possible alternative to integrated instructions. Whereas integrated instructions reduce the extraneous load on working memory, a mixed mode instructional design aims to increase working memory capacity. The learner is still faced with a split attention format and mental integration is still required, however working memory may be effectively increased by presenting information in a dual format rather than a purely visual mode.

Mousavi, Low & Sweller (1995) investigated this modality effect using geometry worked examples. It was hypothesised that the negative consequences of split attention in geometry might be overcome by presenting geometry statements in an auditory form and the related diagram visually. In a series of six experiments, the researchers found that instructions presented in a partly auditory, partly visual format were superior to traditional visual based instructions where diagram and text are physically separate. Similar results have been demonstrated by Mayer & Anderson (1991, 1992) and Mayer & Sims (1994) using a range of technical material. The research by Mayer and his associates suggested that audio/visual instructions presented in a coordinated fashion may be superior to a variety of alternative instructional techniques.

Tindall-Ford, Chandler & Sweller (1997) replicated and extended these findings in the area of electrical engineering. The researchers compared a traditional visual only format to audio/visual instructions. Tindall-Ford et.al. suggested that dual modality instructions may be beneficial when the information to be learnt was intellectually complex (high in element interactivity). It was hypothesised when studying learning materials that involved a high level of complexity (i.e. high element interactivity), an audio/visual format would be superior to a traditional visual only format. However when information was not intellectually demanding (low in element interactivity) instructional design may be of little consequence, since the total load on working memory was unlikely to result in an overload. Results from a series of experiments supported these hypotheses. In areas of high element interactivity audio/visual instructions were superior to conventional visual only instructions. In contrast, in areas of low element interactivity, no significant differences were found between the two instructional groups. To ascertain that results could not simply be attributed to the fact that listening is inherently easier than reading, subjects were asked to either listen (audio/visual group) or read (visual only group) a prose passage on electrical safety. Subjects then answered a series of questions based on what they had either read or listened to. No differences between groups were found, confirming that the benefits of audio/visual instructions could not simply be attributed to listening being easier than reading. To provide support for a cognitive load hypothesis measures of subjective load and instructional effective estimates (see Paas & Van Merrienboer, 1993; 1994) were collected in all experiments. As with instructional material, differences between the two instructional groups were only found in areas of high element interactivity, with learners from the audio/visual group reporting lower levels of mental load than the traditional visual only learners.

Jeung, Chandler and Sweller (1997) examined the concept of visual search with respect to the modality effect. Experimenting with primary school, computer based geometry instructional materials, the researchers showed that when students were required to extensively search diagrammatic information to coordinate audio information (high search), audio/visual instructions were no more beneficial that visual only instructions. Jeung at. al. demonstrated that when instructional materials required high levels of search, the use of simple animation in the form of electronic flashing may reduce search, enhance the coordination of auditory and visual information and improve learning. The results showed that by reducing search by the use of electronic flashing the modality effect may be restored. When instructional material required little search for the coordination of the visual and auditory information, visual prompts were not required. The research indicated that the effectiveness of visual indicators depended on the cognitive load imposed by visual search.

In an experiment using computer based multi media instructions on soldering theory Kalyuga, Chandler & Sweller (in press) further investigated audio/visual instruction and its role in multi media design. The researchers explored the practice of incorporating simultaneous visual and auditory text presentations when referring to diagrammatic information. This practice of duplicating audio information in a simultaneous visual form, has been widely used by educators and multi media instructional designers for many years. In fact, most multi media products for teaching and training regularly use identical simultaneous visual and auditory text when referring to illustrations, diagrams or tables. However there is little evidence to suggest this practice facilitates learning. There were three groups in this experiment; a conventional visual only format (visual diagram/visual text), an audio/visual instructional design (visual diagram/audio text) and audio/visual/visual format (visual diagram/audio text/ visual text). Results confirmed that audio/visual instructions were superior to equivalent visual only format. In addition to this finding, the research indicated that the duplication of identical text in an auditory and visual form, was actually, detrimental to learning. Kalyuga, Chandler & Sweller (in press) argued that one of the duplicated sources of information (visual or auditory explanations) was redundant. The processing of the identical information requires working memory resources and imposes an unneccesary load on working memory. The elimination of the visual textual information which is redundant would restore the modality effect. The research suggested that a dual mode presentation is only effective when the two modes present different information that must be mentally integrated before it can be understood. Subjective ratings of cognitive load supported the test performance results indicating the superiority of audio/visual instructions compared to audio/visual/visual and conventional visual only instructions.

The design of multi media instructions are still largely based on factors other than sound theory and extensive empirical research. The findings from the experiments discussed in this paper may provide valuable guidance for multi media instructions. Using cognitive load theory and the modality effect as the theoretical framework, the experiments suggest the following with respect to designing more effective multi media presentations: (a) audio/visual format has been shown to be superior to visual only format in a wide range of subject areas including, mathematics, electrical engineering, mechanical engineering; (b) when information to be learnt has a high intellectual component, audio/visual presentation is beneficial; (c) alternatively if the material is not intellectually taxing, presenting instructions in a dual modality makes little appreciable difference to learning; (d) when utilising an audio/visual presentation duplicating auditory text in a visual form interferes with learning; (e) under conditions of high search, an audio/visual presentation is only beneficial if visual indicators in the form of electronic flashing are used; (f) in contrast when instructional materials are low in search a standard audio/visual format is satisfactory.

Alternative pathways to Understanding: The role of Rote Learning

Edwina Pollock

It has been previously indicated that several variables are critical to learning: a) the limited cognitive processing capacity of human memory; b) the prior knowledge level of the learner and c) the acquisition of schemata as the foundation of expertise. These factors are not new to educational psychology research (for example Miller, 1956; Ausubel, 1968; de Groot, 1965) and in fact, form the fundamental components of human cognitive architecture. Together these factors have direct implications for instructional design. Education aims to provide students with meaningful understanding, therefore rote learning has long been regarded as a poor teaching method. A complete rejection of rote learning is however, unwarranted because there may be conditions under which rote learning can be useful. The current paper used the framework of cognitive load theory (Sweller, 1988; 1989; 1993; Sweller and Chandler, 1991; 1994; Chandler and Sweller, 1991; Sweller, Van Merrienboer & Paas, 1998) with its foundations based upon the assumptions about cognition outlined above, to investigate the possible role of rote learning in the design of instructional materials. The results of the studies described in this paper show that rote learning does have a legitimate place in education: as the first part of a two phase learning process for inexperienced or novice students. This instructional technique reduces the burden on working memory and fosters the development of schemata.

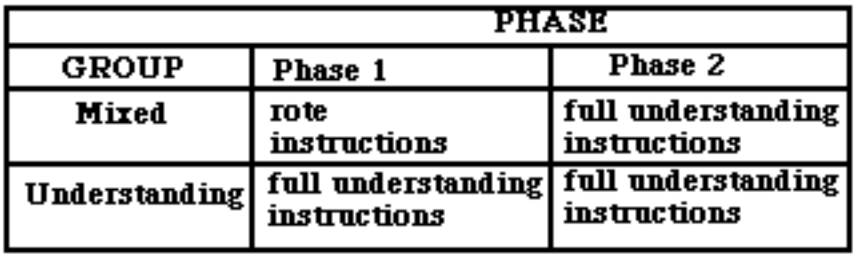
The controversy that the term rote learning is likely to generate requires that terms be very clearly defined. Rote learning may be defined as learning discrete elements of information, without knowledge of the connection between separate elements. For example, learning to label parts of the human body such as the brain, nerves and muscles. In contrast, full understanding is meaningful learning, placing emphasis not only on the elements themselves but upon the interactions between elements and connections to other related information. For example, understanding that movement occurs because the brain sends impulses along the spinal cord and then to a peripheral nerve connecting with a muscle which then contracts to move a joint. Understanding implies that the information has been placed into the student's existing, organised system of knowledge (Ausubel, 1968).

The research this paper describes developed because a theoretical gap seemed to exist. Experts possess knowledge in schemata and their expertise increases as these schema automatise. Yet how does a learner gain schemas? Schema formation requires that all the elements that form a concept have to be able to exist in working memory together. That is, all the elements have to be able to be processed concurrently. Complex concepts have high intrinsic cognitive load, that is, intellectual complexity. This is because of the large degree of interactivity between the elements of information. They are made up of many elements and these elements interact. Prevailing convention assumes that since it is the desire of educators to achieve a final result of meaningful understanding, students should be presented with a concept in all its complexity. Experts, with domain specific knowledge highly organised into schemas, are able to master complex concepts because much of the burden of processing the information is transferred to Long Term Memory. Working Memory load is therefore minimised and capacity is available to allow understanding to develop. If, however, novice students are initially presented with the full understanding instructions of Figure 2, they theoretically possess all the information to understand the concept of earth continuity but may fail to do so because the process of concurrently assimilating all learning elements and their relationships overwhelms working memory. The student is not only failing to understand the concept, they are failing to acquire a schema for the information, thereby limiting future learning also. Thus, educators are often placed in a dilemma because they require students to understand complex concepts, but the students fail to do so because the way teaching materials are structured for understanding prevents students from processing the information through limited working memory.

The question therefore arises: How can we improve the ability of novices to learn complex concepts? This research investigated rote learning as a possible first stage in the process of schema formation. While rote learning in isolation cannot directly lead to understanding, it does allow learners to more easily process information in working memory. Students may be first presented with a basic outline of a concept to learn by rote. For example, in Figure 1 the rote procedure for performing a test of an electrical appliance is displayed. Each step can be learned in isolation without reference to previous steps. While students will not fully understand the complex concept of earth continuity at this stage, they may acquire the rudimentary procedural schemas that will assist them when full understanding instructions are presented. In summary, we predicted that when dealing with complex information, first providing inexperienced students with rote instructions (e.g., Figure 1) *then* presenting them full understanding instructions (e.g., Figure 2) would lead to superior understanding than the traditional approach of immediately presenting students with only understanding instructions.

It should be noted that there are some precedents for the effective use of a rote learning approach in the literature. Hoosain (1983) compared groups who meaningfully learnt or rote memorised classical Chinese passages. Traditionally, literary style classical Chinese passages have been memorised by rote. He found that the rote group exhibited a much better verbatim recall of the passages, which is not unexpected. Interestingly however, the rote group also performed significantly better on comprehension of the passage. Hoosain (1983) explained this performance by the fact that "Rote memorisation, even with only partial understanding, could serve to retain the text in memory while waiting for a future opportunity to unravel meanings" (p. 196).

Two experiments, using material from the field of electrical engineering, will be discussed in this paper. It is important to note that these experiments are part of a body of five experiments, all of which report similar results. There were two groups in each experiment. A conventional 'Understanding' group received full understanding instructions at both phases of instruction (see Figure 2). A Mixed instruction group received rote instructions (see Figure 1) in phase one of the experiment and then full understanding instructions at phase two (see Table 1).



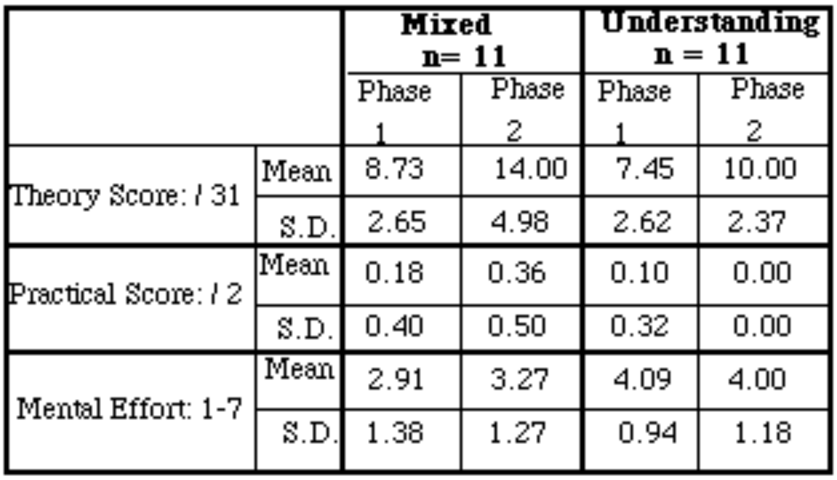
	PHASE	
GROUP	**Phase 1**	**Phase 2**
Mixed	**rote instructions**	**full understanding instructions**
Understanding	**full understanding instructions**	**full understanding instructions**

Table 1: The type of instruction received by each group at each phase

Industrial trainees from a Sydney company participated in both studies. The only difference between the participants in each study was their level of expertise. In Experiment One, trainees with a limited knowledge of electrical principles were tested within their first month of training. Experiment Two used electrical apprentices, who had completed almost half of their first year electrical training. They had a sound knowledge of electrical concepts.

The materials used in this experiment were three electrical tests, used to check the safety of electrical appliances. The procedure for both phases of each experiment were identical. The participants had an unlimited time to study the instructional material. After completing the study, the participants rated mental effort on a 7 point Likert type scale (see Paas and Van Merrienboer, 1993). Participants then preformed a written theory test and a practical transfer task. This procedure was repeated at Phase 2, the only difference being that both groups studied the full understanding instructions. For Experiment 1, it was predicted that a Mixed instruction group (i.e., rote then understanding instructions) would record lower measures of instructional processing time and mental effort and higher test scores (written and practical) than the Understanding only group. In Experiment 2, there was no expected advantages for the Mixed instruction group on the above measures of performance as these more experienced electrical apprentices would already possess many rudimentary electrical schemas.

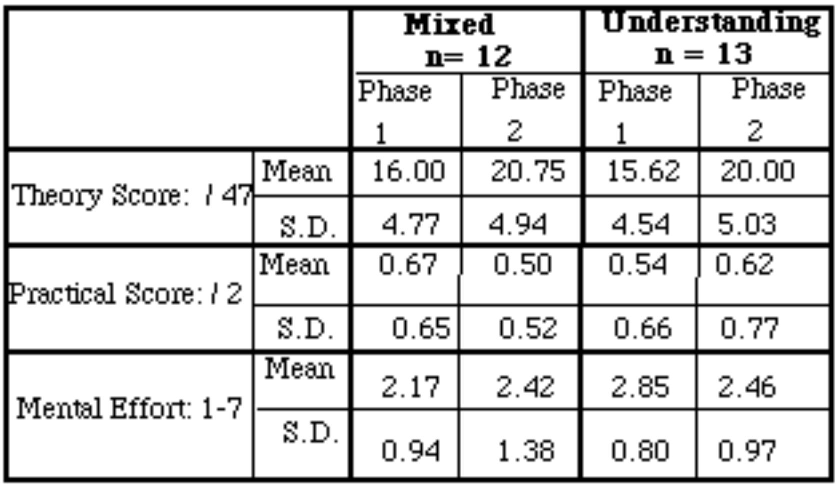
The results strongly supported the hypotheses in both experiments. As predicted, with the more inexperienced learners (Experiment 1) the Mixed instruction group performed significantly better on both theory and practical tests than the group receiving the full understanding instructions at both phases. For Experiment 1, there were differences favouring the Mixed instruction group on written test performance and practical transfer tasks (see Table 2). Furthermore, the Mixed instruction group also rated the mental effort required to understand the instructions as significantly lower than the Understanding group. This result is particularly interesting at Phase 2 where the Understanding group, who study the same set of instructions twice, actually rate their mental effort as higher than the Mixed group, who were studying this set of instructions for the first time (See Table 2). This result supports our theoretical explanation, that is, the rote phase gives the students a partial schema for the information which reduces their working memory burden when faced with the more complex explanation of the concept.



		Mixed n= 11		**Understanding** n = 11	
		Phase 1	Phase 2	Phase 1	Phase 2
Theory Score: / 31	Mean	8.73	14.00	7.45	10.00
	S.D.	2.65	4.98	2.62	2.37
Practical Score: / 2	Mean	0.18	0.36	0.10	0.00
	S.D.	0.40	0.50	0.32	0.00
Mental Effort: 1-7	Mean	2.91	3.27	4.09	4.00
	S.D.	1.38	1.27	0.94	1.18

Table 2: Means and Standard Deviations for Performance, Learning Time and Mental Effort in Experiment 1: Novices

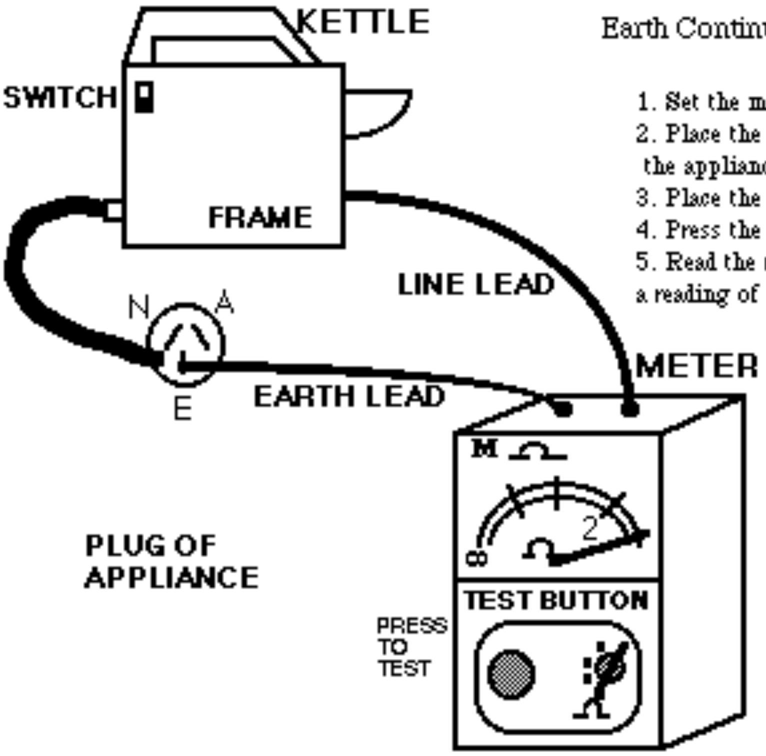
In Experiment 2 with the more expert subjects, the results supported our prediction of no advantage from the Mixed instructional format. No difference was found between the groups in terms of performance on the written test, practical tasks or subjective mental effort ratings (see Table 3).



		Mixed n= 12		**Understanding n = 13**	
		Phase 1	Phase 2	Phase 1	Phase 2
Theory Score: / 47	Mean	16.00	20.75	15.62	20.00
	S.D.	4.77	4.94	4.54	5.03
Practical Score: / 2	Mean	0.67	0.50	0.54	0.62
	S.D.	0.65	0.52	0.66	0.77
Mental Effort: 1-7	Mean	2.17	2.42	2.85	2.46
	S.D.	0.94	1.38	0.80	0.97

Table 3: Means and Standard Deviations for Performance, Learning Time and Mental Effort in Experiment 2: Experts

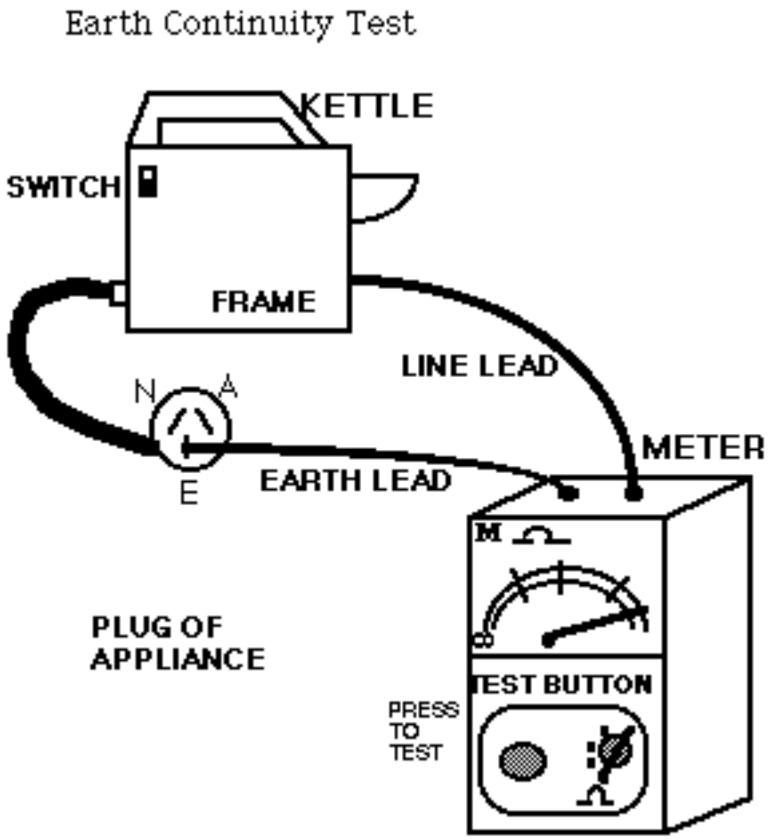
The findings of this research suggest that rote learning may have a role to play in the presentation of instructional materials; it is not however, advocating the use of rote learning in isolation. For inexperienced learners, a rote learning format may be a useful preliminary instructional tool *before*full understanding instructions are introduced. We assume that initially the Mixed group of students did not fully understand the complex concept of electrical safety testing. By reducing the intrinsic cognitive load of the material however, through obviating the need to process all the interacting elements required for understanding in working memory, they acquired the rudimentary schemas for the concept. Subsequently, the interactions between the elements of information could be learned in the second phase allowing a more complete understanding of the material. This research also showed that for more expert learners, rote instructions provide no advantages over full understanding instructions. This is presumably because the more experienced learners already have relevant background knowledge and therefore possess the necessary schemas to make sense of understanding instructions. In summary, the current research has indicated that for the appropriate learners, educators may gain considerable benefits from initially utilising rote learning instructions.



Earth Continuity Test

1. Set the meter to read ohms
2. Place the earth lead from the meter on the earth pin of the appliance's plug
3. Place the line lead on the frame of the appliance
4. Press the test button
5. Read the resistance from the meter. The required result is a reading of less than two ohms

Figure 1: An example of the Rote version of the instructions - the Earth Continuity test



This test aims to check that in the event of a fault, the frame of the appliance does not become electrically active from current which should be directed to the earth. This can be achieved by setting up a circuit including the frame of the appliance and its earth point and measuring the resistance between the two points. Resistance is a barrier which can keep current in the circuit. Ideally, this circuit should have zero resistance.

1. *A megger meter is connected into each circuit to measure the resistance. The ohms setting is used to measure the very small resistances expected of this circuit.* Set the meter to read ohms.
2. *To set up to measure the resistance of the circuit,* place the earth lead of the megger meter on the earth pin of the appliance's plug and then
3. Place the line lead on the frame of the appliance.
4. *When the test button of the megger meter is pressed, a measurement of the resistance of the circuit can be taken from the needle of the meter:* Press the test button.
5. *A resistance reading of less than 2 ohms is sufficiently small to indicate that there is no dangerous barrier in the earth-frame circuit, blocking current from going to the earth point.* Read the resistance from the meter. The required result is a reading of less than two ohms.

Figure 2: An example of the Understanding verion of the instructions - the Earth Continuity test. {The understanding text that was added to this version is written in italics. The same five steps that formed the rote version are also included in this version (normal text).}

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The Application of Mental Rehearsal to Cognitive Domains

Dr Graham Cooper

Mental rehearsal, often termed mental practice, refers to "the introspective or covert rehearsal that takes place within the individual" who thinks through the performance of an activity in the absence of any gross muscular movements (Beasley, 1979, p 473). Use of mental rehearsal has sometimes been observed to result in improved performance on the task in question, indicating that it is a viable pathway for learning. However, mental rehearsal has not always been observed to enhance learning. The dynamics of mental rehearsal and the factors which determine it's effectiveness, remain to be clearly specified.

This paper presents an overview of a cognitive based model of mental rehearsal. Schemas (of the content area in question) are viewed to predominantly define a *prerequisite* to effective use of mental rehearsal. Only after sufficient schemas have been acquired will a learner be able to engage in mental rehearsal of instructional procedures that are accurate and meaningful. It is argued that under these conditions mental rehearsal facilitates the automation of the rules and procedures utilised during the period of mental rehearsal. The results from two experiments demonstrating the successful application of mental rehearsal to a task domain which is essentially cognitive in nature (the learning of basic spreadsheet operations) are briefly discussed.

Historical Review of Mental Rehearsal

Studies demonstrating the successful application of mental rehearsal date as far back as the 1930's (Sackett, 1934; 1935; Perry, 1939), although Sackett referred to it as "symbolic rehearsal", while Perry used the term "imaginary practice". More recently the terms "mental practice" (Clark, 1960), and "covert rehearsal" (Corbin, 1967) have also been used. During the 1960's and 1970's there was a strong interest in the use of mental rehearsal in the context of sports psychology as a possible means of improving performance on a wide range of sports related tasks including sit-ups strength (Kelsey, 1961), tennis swing (Surburg, 1968), hockey swing (Phipps & Morehouse, 1969), serving in volleyball (Shick, 1970), foul-shooting in basket ball (Clark, 1960), rotary pursuit (Rawlings & Rawlings, 1974) and dart throwing (Mendoza & Wickman, 1978). Mental rehearsal techniques have also been applied within interpersonal contexts such as counselling behaviours (Hazler & Hipple, 1981) and clinical examinations (Rakestraw, Irby & Vontver, 1983). While the fever of research into mental rehearsal strategies may have lost intensity in recent years, it does still continue, but still predominately in content areas that are primarily sports related (for example, Grouios, 1992; Ungerleider & Golding, 1991).

Regardless of the terminology used, studies investigating the application of mental rehearsal have often obtained results indicating that students who engage in mental rehearsal of a task improve their performance on that task. Moreover, many studies, though certainly not all, have found that the level of improved performance attained by students who engage in mental rehearsal to be equivalent to the level of improved performance attained by students who engage in actual physical practice of the task (Driskill, Copper & Moran, 1994).

Several arguments have been forwarded to explain why mental practice should be effective. Historically, the two major views have been the "psycho neuromuscular theory" and the "symbolic learning theory". The psycho neuromuscular theory (Jacobson, 1932) argues that mental rehearsal is "simply a sub-threshold arousal of the normal motor output system which is sufficiently strong to generate kinesthetic sensations" (Annett, 1995, p 162). In contrast, the symbolic learning theory (Sackett, 1934) views mental rehearsal to operate by affecting the cognitive aspects of a task. On this basis, the degree to which mental rehearsal can be effective should be dependent upon the degree to which cognitive elements of the task exist. Evidence supporting this view comes from Feltz and Landers (1983) who conducted a meta-analysis of 60 studies (addressing 146 experimental effects) in mental rehearsal. They found that the more cognitive domain orientated the task, the greater the effect. This conclusion has also been voiced by Driskill, Copper & Moran (1994) who conducted a more rigorous meta analysis across 35 studies (addressing 100 experimental effects). Driskill et al (1994) argued that for any task the physical domain should be described in terms of: (1) the involvement of muscular strength, (2) endurance and (3) coordination; while the cognitive domain should be described in terms of: (1) the involvement of perceptual input, (2) mental operations and (3) output and response activities. Using this taxonomy Driskill et al were able to further identify that "for the cognitive domain: the more a task required mental operations, the more effective was mental practice. Outputs and response activities, as well as perceptual input activities were somewhat weaker, yet potent predictors" (1994, p 485).

These observations suggest that mental rehearsal offers the potential of being used as an instructional strategy beyond the domain of sports psychology where a behavioural outcome is the prime objective. It may be that the beneficial effects of mental rehearsal may be most readily manifested in tasks that are wholly, or at least predominantly, cognitive in nature, especially when the role of cognition involves a high degree of mental operations.

Schema Theory, Automation and Mental Rehearsal

Studies investigating expert-novice differences in cognitive domains have identified schemas (Gick & Holyoak, 1980 & 1983) and automation (Kotovsky, Hayes & Simon, 1985) to be the two primary factors determining expert performance (Cooper & Sweller, 1987). Schemas form an hierarchical network of knowledge consisting of both declarative and procedural information. They provide a library of mental constructs which may be used to assist in understanding presented information and "allow patterns or configurations to be recognised as belonging to a previously learned category and which specify what moves are appropriate for that category" (Sweller & Cooper, 1985, p 60). In contrast, automation refers to the development of a procedural activity with decreasing levels of conscious attention (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). Automation, also referred to as 'automaticity', was originally linked to the performance of motor tasks, but the concept has also been applied to the context of cognitive domains (Neves & Anderson, 1981; Kotovsky, Hayes & Simon, 1985; Cooper & Sweller, 1987). Execution of an automated procedure,whether physical or cognitive in nature, is fast, yet requires relatively low levels of conscious processing control; 'without thinking' as it were, and this in turn means that fewer working memory resources are required. The interactive effects of schemas and automation enable experts to solve virtually all problem types within their area of expertise. This is true even for problems which the experts may never have seen before (Cooper & Sweller, 1987).

A primary goal of education and training is to develop suitable instructional materials and activities which will enable novices to make the transition towards expertise. The empirical findings outlined above mean that the quest becomes one of determining how best to facilitate schema acquisition and automation. Insight into the processes by which schemas and automation are acquired comes from current knowledge and understanding regarding human cognitive architecture (see Sweller & Chandler, 1994; Tindall-Ford, Chandler & Sweller, 1997; Sweller, Van Merrienboer, & Paas, 1998).

The present study concerns itself primarily with the prospect of applying mental rehearsal instructional strategies to a content domain that is of a complex cognitive nature. Few, if any studies, appear to address tasks commonly associated with academic pursuits that are aligned with the areas commonly investigated in expert-novice studies. These would include broad content areas such as mathematics, physics, electronics, engineering, computer programming, and, as this study uses, computer software applications.

Also of interest is the specific dynamics by which mental rehearsal operates. Mental rehearsal may be a strategy which is reliant upon schemas having already being acquired, rather than a strategy to assist in their acquisition.This has previously been suggested by Driskill, Copper & Moran who observe that "mental practice may be more effective, everything else held constant, if novice subjects are given schematic knowledge before mental practice of a physical task" (1994, page 489). A consequence of this would be that the effects of mental rehearsal should be mediated by the subjects' level of prior knowledge in the content area; their level of expertise. Subjects who hold a relatively high level of expertise in a given content area may find the application of mental rehearsal techniques to have a beneficial effect on their learning, because their schemas will enable them to conceptualise, maintain, and execute the mental operations associated with mental rehearsal. In contrast, subjects who are novices in a content area may find that attempts to engage in mental rehearsal may impede their learning because they lack the schemas necessary to enable the necessary conceptualisation (or mental imagery) of the instructional material.

The analysis presented above leads to a theoretically critical question: if the two defining factors of expertise are schemas and automation, and mental rehearsal requires schemas to have *already* been largely acquired to be effective, then what is it precisely that is being learnt when successfully engaging in a mental rehearsal strategy? The answer to this question may well lie within a view that describes the benefits of mental rehearsal primarily in terms of facilitating automation. This paper argues that mental rehearsal assists learning primarily by encouraging students to engage in mental modelling, sequencing and chaining of their already held schemas.

Experimental Results

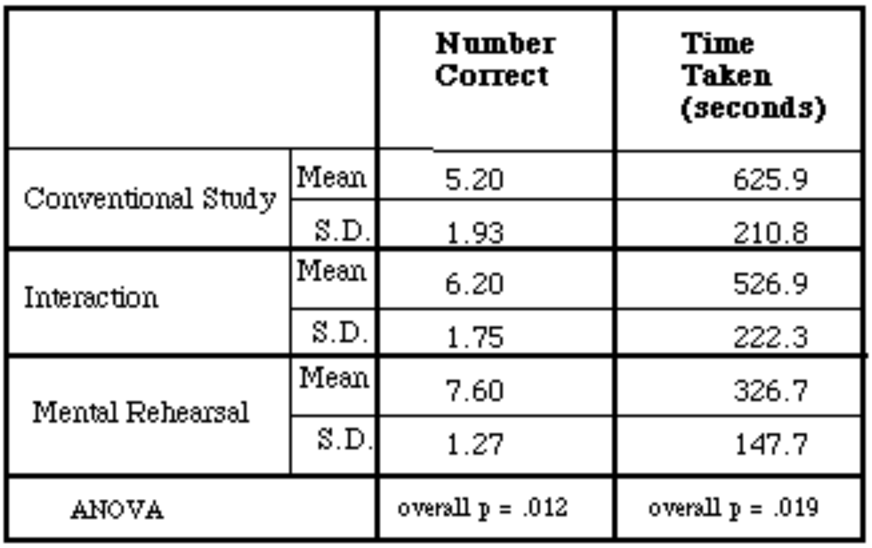
Two experiments which used computer based training programs to present introductory instructional materials on the use of spreadsheets investigated the relative effectiveness of three alternative instructional strategies. The three instructional strategies used may be broadly described as (1) 'conventional study of worked examples' where the emphasis is to*understand and remember procedures* specified by instructional materials; (2) 'interactive simulations of worked examples' where the emphasis is to*perform procedures* specified by instructional materials, and; (3) 'mental rehearsal of worked examples' where the emphasis is to *imagine performing procedures* specified by instructional materials.

Experiment 1

Experiment 1 used 30 Year 7 students who were considered to be highly capable in mathematics. All students had previous experience with computers, but did not have knowledge of computer spreadsheet applications.

In accordance with the theory described above, results from ANOVAs indicated that the performance of the mental rehearsal group was superior to the performance of both the conventional study group and the interactive simulation group (an alpha of .05 was used for all analyses). The mental rehearsal group spent less time overall on test problems, and were able to solve more of them, than the other two groups, which did not differ significantly (see Table 1).

Table 1: Means and standard deviations for number correct and time taken on test problems in Experiment 1



		Number Correct	Time Taken (seconds)
Conventional Study	Mean	5.20	625.9
	S.D.	1.93	210.8
Interaction	Mean	6.20	526.9
	S.D.	1.75	222.3
Mental Rehearsal	Mean	7.60	326.7
	S.D.	1.27	147.7
ANOVA		overall p = .012	overall p = .019

Experiment 2

In Experiment 2 the level of prerequisite knowledge held by subjects was manipulated by comparing the effects obtained in the top classes (54 subjects) to those obtained in the bottom classes (57 subjects). Modifications to the experimental design were made to the effect of exposing subjects to relatively prolonged acquisition periods.

Results from an ANOVA indicated a significant interaction effect between class level and instructional strategy for number of questions solved correctly. Mental rehearsal had a beneficial effect on learning within the top classes, but a detrimental effect within the bottom classes. Separate ANOVAs were subsequently conducted on the top classes and bottom classes.

Within the top classes the mental rehearsal group performed better than both the conventional study group and the interactive simulation group, which did not differ significantly, replicating the results of Experiment 1. However, for the bottom classes, the conventional study group performed better than both the mental rehearsal group and the interactive simulation group, which did not differ significantly (see Table 2).

The results of Experiment 2 are consistent with the view that mental rehearsal may facilitate learning only if sufficient prerequisite schemas are held by subjects. If these prerequisite schemas are absent, then the most beneficial learning strategy may be that which best focuses subjects' attention on the acquisition of those schemas. The most effective and efficient strategy available to subjects for acquiring schemas is expected to have been the study of worked examples (see Sweller & Cooper, 1985; Cooper & Sweller, 1987).

Table 2: Means and standard deviations for number correct on test problems in Experiment 2.

		Top Classes	**Bottom Classes**
Conventional Study	Mean	9.72	9.37
	S.D.	1.18	1.17
Interaction	Mean	9.78	7.74
	S.D.	1.22	1.49
Mental Rehearsal	Mean	10.61	8.32
	S.D.	0.70	1.25
ANOVA		overall p = .025	overall p = .001

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