Using Cognitive Principles to Improve Instructional Procedures

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Abstract

Recent cognitive research indicates that many commonly used instructional techniques are inadequate as they overload limited working memory and interfere with the two primary components of learning, namely, schema acquisition and automation. For example, data are available indicating that instructional formats which unnecessarily split attention between referring sources of information or contain additional redundant sources of information seriously interfere with the learning process (Chandler &
Sweller, 1991; 1992; Sweller, Chandler, Tierney & Cooper, 1990). Several short term experiments and long term field studies in both educational and industrial settings have shown that alternative, cognitively based instructional packages designed to reduce the burden on working memory are superior to traditional techniques used by educators for generations. This paper explores the conditions under which these alternative instructional techniques are likely to be most beneficial. It suggests that when information has a high intellectual component, then the instructional format becomes critical and cognitively based instruction is highly effective. Where the intrinsic nature of the information imposes fewer intellectual demands, then the format of instruction is not as important (Sweller & Chandler, in press). A number of studies which support these hypotheses using computer based materials and other technical based equipment are discussed.

Over the past few decades there have been clear indications of general agreement among cognitive theorists concerning many of the basic mechanisms involved in higher intellectual activities. While a broad model of human mental processing is gaining acceptance, many conventional instructional techniques violate the most basic assumptions of the model and may be inadequate. The research reported in this paper tests the viability of alternative instructional techniques, more in accord with our cognitive processes. Before detailing this research, I will discuss some widely accepted cognitive structures.

Some Aspects of Human Cognitive Architecture

Everything that we learn interacts with either working memory, long-term memory or both. Working memory is where current mental activity takes place. It is both limited in duration and
critically, for present purposes, very limited in capacity (Miller, 1956; Simon, 1974). Modern conceptions of working memory (e.g. Baddeley, 1992) suggest that it is not a single, undifferentiated entity but rather, may consist of multiple stores. Separate auditory and visual stores have been suggested. Baddeley, for example, suggests a discrete auditory store for handling verbal information and a separate visual store for handling visual images. While modern accounts pay more attention to the processes involved in working memory instead of storage considerations (also see Halford, Wilson, Wiles & Stewart, in press), all still emphasise its very limited capacity.

In contrast to working memory, long-term memory is huge, with unknown limits. Surprisingly, a full realisation of its more important characteristics such as its enormous capacity only occurred in the last two decades and is a major finding of the cognitive science revolution. We now know that many of the cognitive activities and skills that previously were thought to be strongly associated with working memory are a function of an enormous knowledge base held in long-term memory. For example, since De Groot (1965) and Chase and Simon (1973), it has become apparent that the skill of chess masters does not derive from their use of working memory to engage in complex search activities. Rather, the use of long-term memory to recognise board configurations and remember the best moves associated with each configuration is the essential cognitive characteristic associated with problem solving skill. Simon and Gilmartin (1973) estimated that experts in complex areas such as chess have remembered tens of thousands of problem states and their associated moves. It is this store of information that is the source of expertise.

Mechanisms of learning interact closely with working and long-term memory. When dealing with higher intellectual functioning, there are two mechanisms of learning that are critical: Automation and schema acquisition. Automatic processing (Shiffrin & Schneider, 1977; Schneider & Shiffrin, 1977; Kotovsky, Hayes & Simon, 1985) allows mental processes to occur smoothly, rapidly and without conscious control. It requires long periods of practice during which procedures can occur only under conscious control. Controlled processing places a burden on working memory that automatic processing reduces. A major function of automation seems to be to by-pass our limited capacity working memory.

The second learning mechanism is schema acquisition which also by-passes working memory by using long-term memory. The concept of a schema, discussed by Bartlett (1932), is now widely used in cognitive psychology. Consequently, many varying definitions of a schema exist (e.g., Thorndyke & Hayes-Roth, 1979; Gick & Holyoak, 1983), each inevitably reflecting the theoretical perspective of the proposer. For the purposes of this paper, a schema will be
viewed as a cognitive construct that categorises information according to the manner with which it is dealt. For example, we recognise common objects such as cats almost instantaneously because we do not need to process more than a small amount of what we see, with our schemas filling in the rest. We can rapidly read many different types of text because the marks on the page, even if unique in the case of handwriting, correspond to previously acquired schemas. Similarly, we can solve problems in areas in which we are expert because our schemas allow us to categorise each problem according to its solution moves. For example, consider the algebraic problem: \(2y - 3 = 5\). A competent mathematics student will categorise this problem as one that first requires a number to be added to both sides (in this case 3) and then divided by a number (in this case 2). Notice that the problem is categorised according to solution mode, irrespective of the numerals and pronumerals involved in the problem. The schema required to solve this problem can be applied to solve an infinite number of expressions in this category (e.g., \(3t - 9 = 3\) or \(6h - 1 = -7\)). (See Koedinger and Anderson, 1990 for a computational model demonstrating the use of schema based solutions in mathematical problem solving). The chess grand masters discussed above derived their expertise from their thousands of previously acquired schemas. Thus schemas, stored in long-term memory, obviate the need to process large amounts of information in limited capacity working memory. When automated, they permit us to deal with huge quantities of information quickly and easily in a manner that is impossible if we are forced to rely solely on working memory (see Low & Over, 1992 for techniques for detecting schemas).

Instructional Consequences of our Cognitive Architecture

This architecture has consequences for instructional design. Instruction should be directed to facilitating schema acquisition and automation without imposing a heavy cognitive load that exceeds the processing capacity of working memory. There are two general sources of cognitive load. Firstly, extraneous cognitive load can be brought about by instructional designs that require students to engage in activities irrelevant to schema acquisition and automation. Secondly, some subject matter, because of its nature, imposes an intrinsic cognitive load.

This section is concerned with extraneous cognitive load that is amenable to reduction by appropriate instructional designs. Cognitive load theory (Sweller, 1988, 1989, 1993) has been used to identify some traditional instructional procedures that impose a heavy, extraneous cognitive load. Two of several effects (see Sweller & Chandler, 1991 for details of other effects) generated by this research have given rise to alternative instructional
techniques designed to reduce extraneous cognitive load and facilitate schema acquisition and automation. These are very briefly summarised below.

The Split-attention Effect. Research indicated that some worked examples and instructional materials are ineffective because they impose a heavy extraneous cognitive load. The conventional mode of presenting some worked examples and instructional materials require students to mentally integrate disparate sources of information before the example can be processed. For example, consider the conventional instructional format shown in figure 1. Before this electrical material can be understood, the diagram of the electrical appliance and associated statements must be mentally integrated and this continuous search and match process is mentally taxing. The heavy cognitive load is imposed solely because of the structure of the materials. Physically integrating the diagram and statements by placing the statements on the diagram eliminates the need for mental integration and thus reduces extraneous cognitive load (see figure 2). Tarmizi and Sweller (1988), using geometry, and Ward and Sweller (1990), using physics, demonstrated the superiority of integrated worked examples over conventional worked examples.

Furthermore, Sweller, Chandler, Tierney and Cooper (1990), Chandler and Sweller (1991) and Chandler and Sweller (1992) found advantages for integrated instructional formats over conventional "split-source" formats using initial instructional materials in a wide variety of training areas in both educational and industrial settings. The fact that the effect was demonstrated in unrelated areas such as Numerical Control programming, electrical installation testing and human anatomy in both laboratory and long term field studies suggests that the elimination of the split-attention effect has wide-spread applications.

The Redundancy Effect. Cognitive load theory suggests that not all split sources of information should be integrated. Integration is required where the multiple sources of information are unintelligible in isolation. In many cases, individual sources of information are not only intelligible in isolation but provide all of the information required. Many biological and electrical wiring diagrams are self-contained with text that merely recapitulates the information in the diagram. For example, consider the instructional material in figure 3, describing blood flow around the heart, lungs and body. The diagrammatic information is completely self-contained with the additional textual information merely describing the path.
Chandler and Sweller (1991) and Bobis, Sweller and Cooper (1993) demonstrated that the elimination rather than integration of such redundant sources of information facilitates learning. Processing redundant information imposes an extraneous cognitive load that interferes with the learning process. As with the split-attention effect, the redundancy effect seems to be a quite general phenomena that has been demonstrated in the disparate areas of electrical wiring, paper folding and biology. Indeed, as Sweller (1993) pointed out, it seems to have been demonstrated on many occasions by many researchers over a long period of time.

Intrinsic Cognitive Load

The work described in the previous section was concerned with extraneous cognitive load that could be manipulated by instructional design. Instructional material also has an intrinsic cognitive load that is impervious to design principles. Material may be difficult to learn because, while the total amount of information may not be large, substantial parts of it must be assimilated simultaneously (see Maybery, Bain & Halford, 1986 for work on the consequences of having to process excessive amounts of information simultaneously). Such material imposes a heavy cognitive load that in this case, is intrinsic rather than extrinsic (see Sweller, 1993). It should be noted that intrinsic cognitive load is unrelated to the total amount of material that must be learned. Material may be difficult to learn because, in total, it contains a large amount of information that must be assimilated serially. I am not concerned with this source of difficulty in this paper because it has no cognitive load implications.

Cognitive load theory asserts that the degree of element interactivity determines intrinsic cognitive load. An element is anything that needs to be learned. The elements of some material can be learned independently of each other. For example, when learning the vocabulary of a foreign language, the translation of each word can be learned largely independently of every other word. A second language translation of the word "chair" can be learned without needing to know the translation for the word "table". The task is difficult because there are a large number of words that need to be learned, not because learning each word is difficult. Intrinsic cognitive load is low in this task. In contrast, learning the syntactic and semantic characteristics of a foreign language imposes a much heavier intrinsic cognitive load because of element interactivity. The elements that constitute syntactical rules cannot be learned in isolation but rather, must be learned simultaneously because they interact. For example, in English, word
order is important. We must say word order is important not word order important is or important is word order. Learning appropriate word orders requires simultaneous consideration of all of the words in the phrase because the words (or elements) interact. In this case, intrinsic cognitive load is high.

While intrinsic cognitive load, unlike extraneous load, cannot be eliminated by instructional design, it is important because it interacts with extraneous cognitive load. From the point of view of a learner, intrinsic and extraneous cognitive load are indistinguishable. Thus, if the total cognitive load is low and does not exceed the working memory capacity of a particular learner because the intrinsic cognitive load is low, the fact that the instructional design used is not optimal may have few adverse consequences. In contrast, with a high intrinsic cognitive load due to high element interactivity, any additional load caused by inappropriate instructional designs may be critical.

Previous work using cognitive load theory has used high element interactivity material. There now are clear theoretical grounds for hypothesising that the split-attention and redundancy effects described above will be reduced or eliminated using materials with lower levels of element interactivity but maintained with instructional materials that involve a high degree of element interactivity. The relations between element interactivity, extraneous cognitive load and instructional techniques will be discussed in the next sections.

Learning to Use Computing and Technical Equipment

The studies to be reported in this paper examined the relations between element interactivity and extraneous cognitive load using various computer packages. Sweller and Chandler (in press) observed that the conventional method of introducing learners to new computer applications such as cad/cam, word processing and spreadsheet packages is fairly stereotyped and widely accepted, yet may have serious negative consequences for learning. Most computer manuals consist of instructions that will require the use of the computer keyboard and attention to information on the computer screen. For instance, consider the conventional format for learning a cad/cam (computer aided design/computer aided manufacture) package shown in Figure 4. To learn the new computer package, the novice must split his/her attention between and mentally integrate information from the manual, screen and keyboard. Thus, we have an obvious split-attention situation, where a continuous series of mental integrations between instructions in the manual, screen and keyboard are required to render the material intelligible. This ongoing process of mental integration is likely to impose a heavy extraneous cognitive load.
An alternative method of presentation designed to reduce the extraneous load on working memory and facilitate domain specific knowledge of computing principles. A seemingly counter-intuitive yet theoretically motivated approach involved eliminating the computer during the critical, initial instructional period. The hardware can be replaced by diagrams of the computer screen and keyboard. As indicated in Figure 5, the textual manual instructions are physically integrated at their appropriate locations on the diagram. To follow this modified self-contained manual one simply follows the numerically ordered steps.

Thus, a test for a split-attention effect could be made by comparing a conventional manual and computer format with an integrated, self-contained modified manual only format. Furthermore, since a modified manual is completely self-contained, then its contents are intelligible without reference to the computer. In fact, when one studies a modified integrated manual, the computer itself is redundant. A test for the redundancy effect could be made by comparing a self-contained manual format with a self-contained manual that also includes the computer.

It was predicted that split-attention and redundancy effects would only be expected in areas where the instructional material involved a high level of element interactivity. No such effects were expected in areas of low element interactivity. A group of four experiments, employing both computing based materials as well as electrical engineering instructions, tested these hypotheses. There were three groups in the experiments, namely, an integrated manual only group, a conventional manual plus computer/equipment group and an integrated manual plus computer/equipment group. The experiments were conducted within Sydney high schools and private companies. The computer packages utilised were commonly used spreadsheet, word processing and cad/cam packages. The packages utilised contained instructions with varying degrees of element interactivity. For example, cad/cam packages tend to have areas of both high element interactivity and low element interactivity. Most cad/cam software contains a large number of individual elements to be learned such as using grids, scales, moving the cursor in various size steps, etc. These individual tasks can be learned quite independently of each other. There is little, if any, interaction between learning elements. For example, to activate a specific grid one needs to learn only one single element, namely, to press the appropriate function key. This task can be learned without considering the
function of any other key.

However, in order to use the more complex aspects of any CAD/CAM system, a novice must learn to use a coordinate system that is designed to enable location and movement of objects (see Chandler, Waldron & Hesketh, 1988 or Hesketh, Chandler & Andrews, 1988). The coordinate system must be learned as a single, large unit. It is not possible to learn how part of the system works before progressing to the next part. Rather, the entire system needs to be learned and understood before any of it can be used. This is an area of high element interactivity for novices learning CAD/CAM systems. For example, to move the position of an object using a CAD/CAM package many learning elements need to be simultaneously considered.

The pattern of results were consistent for the four experiments. In areas of high element interactivity, an self-contained integrated manual studied in isolation proved superior to a conventional manual plus computer/equipment group and an integrated manual plus computer/equipment group. The differences between the groups in both written and practical skills were quite dramatic with little overlap between the groups in some experiments. No split-attention and redundancy effects were demonstrated in areas of low element interactivity. Sweller and Chandler (in press) explained the results from these four experiments in terms of intrinsic cognitive load generated by varying degrees of element interactivity. We claimed that when there is a high level of interaction between individual learning elements, and therefore a relatively heavy intrinsic cognitive load, then the extraneous cognitive load imposed by the presentation technique becomes critical. A modified self-contained manual format designed to reduce extraneous load was claimed to be beneficial under these circumstances. However, in areas where element interactivity was low, and consequently intrinsic cognitive load low, then the extraneous load resulting from the method of presentation was relatively inconsequential.

While the findings of Sweller and Chandler (in press) were encouraging in terms of providing alternative instructional techniques more in accord with our cognitive architecture, there was a need to provide more direct, empirical evidence that the results were due to cognitive load rather than some other factors. A further study was therefore conducted to extend the findings of Sweller and Chandler (in press) by examining the above hypotheses with more detailed instructional materials and a more rigorous testing phase. The major objective, however, was to provide support for the cognitive load hypothesis by providing an empirical measure of element interactivity and cognitive load. Measures of cognitive load will be discussed in the next section.

Measuring Element Interactivity and Cognitive Load
Measuring Cognitive Load Using Secondary Tasks

Empirical measures of cognitive load have received attention recently. For example, Paas and Merrienboer (in press) obtained evidence that subject ratings of cognitive load can be effective. In addition, there exists a considerable, earlier body of literature investigating cognitive load through the use of dual-task paradigms. These studies used performance on a secondary task to assess cognitive load associated with a primary task. Britton and his associates used reaction times to a click as a secondary task with a group of primary reading tasks varying in terms of cognitive complexity (Britton, Glynn, Meyer & Penland, 1982; Britton, Holdredge, Curry & Westbrook, 1979; Britton & Tesser, 1982). Their studies found that performance on the secondary task could be used as an indicator of the cognitive capacity demanded by the primary task. Lansman and Hunt (1982) also used secondary reaction time tasks to indicate the cognitive load required by a primary task. They found reaction time could provide a measure of spare cognitive capacity when subjects performed a relatively easy primary task. This information was used to successfully predict a subject’s performance on a later, more complex task. Book and Garling (1980) and Lindberg and Garling (1982) found that the secondary task of counting backwards while traversing a path had a debilitating effect on locational knowledge relating to the traversed path. Fisk and Schneider (1984) using concurrent tasks, found that increasing a subject’s attention to one task during controlled processing reduced long-term memory on a second task.

This research suggests that performance on a secondary task can be used as a valid indicator of the cognitive load associated with a primary task. Nevertheless, it needs to be noted that many of the experiments cited above were carried out without reference to current conceptions of working memory. If, as suggested by Baddeley (1992), humans have multiple working memory stores, then it may be important to ensure that the secondary task accesses the same store as the primary task. For example, reaction time to a tone while engaged in a visually based task may not be as effective as a secondary task that bears a greater similarity to the primary task. Effects may be greater if both tasks affect the same working memory store.

With respect to the current paper, secondary task performance was used to measure the cognitive load associated with learning different aspects of cad/cam software. The secondary task used was conducted on a separate computer. On this computer, a tone sounded which was immediately followed by a letter appearing on the computer screen. The actual secondary task was to recall the
previous letter seen on the screen, while encoding the new letter. It was predicted that accuracy of recall would be strongly related to the level of cognitive load on the primary task which was to learn aspects of the cad/cam system. Because both the primary and secondary tasks involve visually based reading materials, it was assumed that the secondary task would be particularly sensitive to changes in cognitive load on the primary task. In other words, in areas of high element interactivity, a self-contained modified manual only group was expected to show stronger secondary task performance than the conventional cad/cam manual plus computer and modified manual plus computer groups, because of the reduced extraneous load involved with the self-contained instructional format. No such differences were predicted in areas of low element interactivity because the total cognitive load may not exceed working memory limits even when the instructional design imposed a relatively heavy cognitive load. These hypotheses were confirmed. Strong primary (written and practical) and secondary task effects favoured a integrated modified manual group in areas of high element interactivity. No such effects were found in areas of low element interactivity.

Discussion

The findings of the experiments presented in this paper are consistent with cognitive load theory. In areas of high element interactivity, the self-contained modified manual format demonstrated its superiority over the conventional manual plus computer format and the modified manual plus computer format. Strong split-attention and redundancy effects were exhibited with high element interactivity cad/cam instructional materials. The sometimes dramatic differences favouring the self-contained format were found in both written test performance and practical tasks. The practical task results are of particular significance, considering that the self-contained modified group had no previous access to the computer prior to testing. On the other hand, the other two groups were unable to repeat the practical tasks in the test period that they successfully completed in the instruction period. In contrast to these findings, there was absolutely no evidence of differences between the groups in areas of low element interactivity. In fact, all three groups performed quite evenly in both written and practical tests in low element interactivity domains.

I believe that cognitive load theory can best explain the seemingly counter-intuitive results of this experiment. It has been asserted that when there is a high level of interaction between individual elements, and consequently a heavy intrinsic cognitive load, then
the extraneous cognitive load imposed by the instructional format becomes critical. It was further asserted that a conventional manual which splits attention and mental resources between the manual, computer screen and keyboard would impose a further load on limited working memory. Similarly, a modified manual plus computer would also impose an unnecessary, extraneous load since cognitive resources must be devoted to matching components from a self-contained manual onto the computer. Under both these instructional formats, total cognitive load was predicted to overwhelm the available cognitive capacity of the learners. The consequence is learning inhibition as demonstrated in the current experiment. In contrast, a self-contained modified manual designed to reduce extraneous working memory load, should free cognitive resources allowing students to learn the high element interactive aspects of CAD/CAM applications. This suggestion was also reflected in the results.

While there were clear expectations that a self-contained format would outperform the other groups in areas of high element interactivity, no such predictions were made in areas where there was little or no interaction between learning elements. Under these conditions, it was predicted that the intrinsic cognitive load would not be sufficiently heavy to make the extraneous load imposed by the instructional format important. Consequently, no differences were expected in areas of low element interactivity, a result that was also demonstrated in this study.

The findings of the secondary task experiment provided strong evidence that the primary task results were due to cognitive load. I predicted if instructional material involved little or no interaction between individual elements, then intrinsic cognitive load would be low. The added extraneous load imposed by differing instructional formats may not substantially impair performance on the secondary task because sufficient working memory capacity should be available to perform the secondary task at a high level irrespective of instructional format. This result was obtained. All three groups had little difficulty on the secondary task during the low element interactive sections of the instructional material, suggesting that cognitive load was relatively low at this time.

It was also predicted in the secondary task experiment that when dealing with high element interactivity materials, the extraneous load imposed by instructional format would be a critical factor. I expected that the self-contained, modified manual format would exhibit better letter recall than the other two instructional formats, as the self-contained format was designed to reduce high extraneous load, and hence total cognitive load. Again, the results were as predicted. The secondary task performance of both the conventional manual plus computer and the modified manual plus computer groups were reduced dramatically with high element
interactivity instructions. Accuracy of recall was halved as both groups had considerable difficulty with the secondary task under these conditions. In contrast, the modified manual only format displayed only a small reduction in recall accuracy. As intrinsic cognitive load was the same for all groups, the findings strongly indicate that extraneous cognitive load is reduced by a self-contained modified manual format. The secondary task experiment, by directly measuring cognitive load via a secondary task has confirmed, in effect, that cognitive load is the primary cause of the split-attention and redundancy effects.

The findings of this paper have direct implications for instructional design. It has been demonstrated that the traditional method of instruction in computing areas may not always be beneficial. Under circumstances where instructional materials make considerable intellectual demands (high element interactivity), then the temporary removal of the hardware may facilitate learning. A self-contained manual in which disparate information is physically integrated may be a more viable alternative to more conventional methods that employ a hands-on approach. Based on the results of this study, instruction time can be reduced and learning enhanced, in some areas dramatically, through the use of a self-contained integrated format.

It is important to note that I do not claim that hands-on experience is unnecessary. On the contrary, some exposure to the hardware is likely to be motivating and an integral part of computing instruction. However, our findings suggest the timing of presentation is critical. When dealing with areas of low element interactivity, instructional formats seem to be inconsequential. Exposure to computing equipment may be more useful at these times. Also, if large amounts of high element interactive material need to be assimilated then intermittent exposure to the computer may prove advantageous. This obviously is an area that requires further research.

While the results of these studies are encouraging, there are domains where our findings may not be applicable. For instance, in areas where tasks entail detailed motor components (e.g., operating machinery or performing medical surgery) then a hands-on approach is obviously necessary. I believe the findings are more relevant to learning areas where the intellectual component plays a crucial role and the motor skills involved are quite trivial, as was the case in the current studies.

It is also worth noting that while restructuring of instructional materials for an integrated modified manual is a relatively manageable task, identifying the conditions under which benefits will follow from restructuring is a more complex process. The prior knowledge of the learner plays a critical role in this process. What constitutes a single element for one person may be many elements for another. For example, in the current study, an astute mathematician and/or a person with previous exposure to cad/cam systems with a fully automated schema of the relevant coordinate
system would perceive the system as a single element. Thus, an assessment of learner's knowledge is desirable in determining if alternative instructional formats are likely to be beneficial.

In summary, this paper has tested the viability of an alternative instructional formats based not on tradition or conventional wisdom, but on cognitive load theory. Using various computer packages and electrical engineering materials, the superiority of a cognitively guided formats was demonstrated in areas where high intellectual demands are made. Strong evidence was obtained indicating that the various findings were due to cognitive load factors. It can be concluded that under some circumstances, the removal of computing equipment during critical phases of learning may provide considerable benefits.

References


Table 1

Written Test Scores
(Excludes Problems 4 and 6)

<table>
<thead>
<tr>
<th>Written Test Problem Scores</th>
<th>1 ( /7)</th>
<th>2 ( /2)</th>
<th>3 ( /2)</th>
<th>5 ( /3)</th>
<th>7 ( /3)</th>
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<tr>
<td>Conventional Manual Plus Computer Group</td>
<td>Mean</td>
<td>4.0</td>
<td>0.7</td>
<td>0.1</td>
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<td></td>
<td>SD</td>
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<td>0.9</td>
<td>0.3</td>
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<td>Modified Manual Plus Computer Group</td>
<td>Mean</td>
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<td>0.2</td>
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<td>SD</td>
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<tr>
<td>Modified Manual Only Group</td>
<td>Mean</td>
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<tr>
<td></td>
<td>SD</td>
<td>1.8</td>
<td>1.1</td>
<td>0.6</td>
<td>0.5</td>
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High (H) or Low (L) | (L) | (L) | (L) | (H) | (H) |
Element Interactivity
Table 2
Number of apprentices successfully completing Problem 4 and the individual steps of Problem 5

<table>
<thead>
<tr>
<th>N</th>
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<th>Problem 5</th>
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<td>Step 2</td>
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<td>Plus Computer Group</td>
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<td></td>
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<tr>
<td>Plus Computer Group</td>
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<tr>
<td>Modified Manual</td>
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<td>6</td>
</tr>
<tr>
<td>Only Group</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High (H) or Low (L)</td>
<td>(L)</td>
<td>(H)</td>
</tr>
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Element Interactivity

Table 3
Number of apprentices successfully completing the individual steps of Problems 6 and 7

<table>
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<th>Problem 7</th>
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<td>Step 1</td>
<td>Step 2</td>
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<tr>
<td>Step 2</td>
<td>Step 3</td>
<td></td>
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<tr>
<td>Plus Computer Group</td>
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<td></td>
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<tr>
<td>Modified Manual</td>
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</tr>
<tr>
<td>Only Group</td>
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<tr>
<td>High (H) or Low (L)</td>
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<td>(H)</td>
</tr>
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</table>
Table 4
Number of apprentices successfully completing the individual steps of Practical Task 3

<table>
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<th>Step 2</th>
<th>Step 3</th>
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<tr>
<td>Modified Manual</td>
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</tr>
<tr>
<td>Only Group</td>
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</table>

Element Interactivity

Table 5
Percentage of correct responses on the secondary task during the instructional phase
Level of Element Interactivity

<table>
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<th>Low (Mean)</th>
<th>High (Mean)</th>
</tr>
</thead>
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<td>80.1</td>
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<td>Plus Computer Group</td>
<td>9.6</td>
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<td>82.2</td>
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<tr>
<td>Only Group</td>
<td>6.3</td>
<td>8.5</td>
</tr>
</tbody>
</table>

Appendix 1: Estimate of number of elements for the Low Element Interactivity Material (Elements interact within each section but not between sections)

- Moving the cursor in 1 millimetre steps
  1) Press one of 4 arrow keys (4 non-interacting elements)
- Moving the cursor in 10 millimetre steps
  1) Hold down the shift key
  2) Press the appropriate arrow keys the required number of times
- Moving the cursor in 0.1 millimetre steps
  1) Hold down the control key
  2) Press the appropriate arrow keys the required number of times

Activate a 10 millimetre by 10 millimetre grid

Press the F1 key

Activating the grid lock

Press the F2 key

Using menu functions to move cursor in 10 millimetre steps

1) Activate grid lock
2) Press the appropriate arrow keys the required number of times

Using menu functions to move cursor in 1 millimetre steps

1) Deactivate grid lock
2) Press the appropriate arrow keys the required number of times

Indicate the starting position of a line

Press the space bar

Drawing a line between two positions

Press the return key

Appendix 2: Estimate of number of interacting elements for the High Element Interactivity Material

Movement between any two positions using the CAD/CAM package

1) Read horizontal axis value for current position
2) Read vertical axis value for current position
3) Find position of the goal co-ordinate on the horizontal axis
4) Find position of the goal co-ordinate on the vertical axis
5) Find point of intersection for the goal horizontal and vertical positions
6) Calculate the difference between the current and goal positions on the horizontal axis
7) Press keys appropriate to value calculated in 6
8) Calculate the difference between the current and goal position on the vertical axis
9) Press keys appropriate to value calculated in 8

List of Figures

Figure 1 : An example of the conventional instructions
Figure 2: An example of the modified instructions