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Why Some Material Is Difficult to Learn

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The experiments reported in this article flow from the following assumptions concerning our cognitive processes: (a) Schema acquisition and automation are major learning mechanisms when dealing with higher cognitive activities and are designed to circumvent our limited working memories and emphasize our highly effective long-term memories. (b) A limited working memory makes it difficult to assimilate multiple elements of information simultaneously. (c) Under conditions where multiple elements of information interact, they must be assimilated simultaneously. (d) As a consequence, a heavy cognitive load is imposed when dealing with material that has a high level of element interactivity. (e) High levels of element interactivity and their associated cognitive loads may be caused both by the intrinsic nature of the material being learned and by the method of presentation. (f) If the intrinsic element interactivity and consequent cognitive load are low, the extraneous cognitive load caused by instructional design may not be very important. In contrast, extraneous cognitive load is critical when dealing with intrinsically high element interactivity materials.

These assumptions are the basic points of cognitive load theory. They were used to suggest that, when learning to use equipment such as computer applications, learning might be facilitated by not having the equipment present, if the material that needed to be learned had an intrinsically high degree of element interactivity. A series of four experiments supported this hypothesis. It was concluded that an analysis of both intrinsic and extraneous cognitive load can lead to instructional designs generating spectacular gains in learning efficiency.

The difficulty we face in learning can vary dramatically, depending on circumstances. Although the source of complexity is frequently obvious, at other times it can be obscure. We anticipate that, if new material contains a large amount of information, it will be harder to learn than material containing less information. Nevertheless, we know that students can often find seemingly limited amounts of material immensely hard to assimilate. We might class such material as

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incorporating intractable concepts or procedures, but such classification does not explain the source of the problem. In this article, we suggest: (a) natural origins of difficulty in assimilating information; (b) other sources of difficulty that are artificial and, therefore, likely to be amenable to alleviation by instructional manipulations; and (c) procedures designed to reduce difficulty. In addition, we provide empirical support for the efficacy of our instructional designs. We begin by briefly outlining those aspects of human cognition that govern our theorizing.

SOME RELATIONS AMONG LONG-TERM MEMORY, WORKING MEMORY, SCHEMA ACQUISITION, AND AUTOMATION

In recent years, considerable work has been devoted to explicating relations among learning, problem solving, and human cognitive architecture (e.g., Anderson, 1993). Humans have a huge long-term memory, and it is probably long-term memory with its knowledge store that provides the basis of intellectual skill. Initial evidence for the importance of long-term memory in intellectual performance came from De Groot's (1965) well-known studies of chess skill. He found that more highly skilled chess players were better able to reproduce briefly seen board configurations taken from real games than less skilled players. Chess masters recognize thousands of configurations from previous experience and know which moves are suitable for each configuration. Since De Groot, similar results have been obtained in several intellectual disciplines (e.g., Egan & Schwartz, 1979; Jeffries, Turner, Polson, & Atwood, 1981; Sweller & Cooper, 1985). Studies of expert–novice differences in a variety of contexts have firmly established the critical importance of long-term memory as a source of intellectual skill.

Extensive long-term memory can be contrasted with limited working memory. G. Miller (1956) indicated that we can deal with no more than about seven items of information at a time, whereas Simon (1974) suggested the number of items is closer to five. Either of these numbers can be exceeded by a simple artificial intelligence program. Clearly, our intellectual ability does not reside in our working memory.

We suggest that, in humans, learning mechanisms that contribute to our intellectual skill have the primary function of circumventing our limited working memory and emphasizing our long-term memory. We suggest that other than simple conditioning mechanisms, schema acquisition and transfer from controlled to automatic processing are the major learning mechanisms. Both meet the condition of reducing the burden on working memory.

A *schema* is defined as a cognitive construct that organizes information according to the manner in which it will be dealt. (Bartlett, 1932, provided an early statement of schema theory. Koedinger & Anderson, 1990, provided a computational model demonstrating the use of schema theory in geometry problem solving. Low & Over, 1990, 1992, provided techniques for detecting schemas.) This definition can be used to provide the following examples: A problem-solving schema categorizes problems according to solution mode and so can generate solutions (e.g., Chi, Glaser, & Rees, 1982); a schema for reading text organizes information according to its meaning and so permits us to extract content by looking at only some of the letters and words and allowing the schema to fill in the rest; a schema for recognizing an animal allows us to categorize it as a cat despite only briefly seeing some aspects of it. It is possible that most knowledge is encapsulated in schemas. In addition, note that the schema theory framework used here is closely related to work on situated cognition (Lave, 1988). In both cases, the centrality of domain-specific knowledge is emphasized.

Schemas reduce cognitive load by permitting us to ignore most of the information impinging on our senses. We have schemas that allow us to recognize each tree that we see as a tree despite the fact that all trees differ. The infinite variety of trees can be ignored because of our schemas. We cannot store the immense detail of information presented by a tree in our working memory but, because of our tree schema in long-term memory, we do not need to do so.

As an example of a problem-solving schema, someone who is competent at algebra will have a schema for multiplying out a denominator. The schema will tell that person which of the infinite variety of algebraic equations is amenable to multiplying out a denominator and the procedure for doing so. When faced with a problem such as $a/b = c$, solve for a, we can immediately solve such a problem, despite the many forms in which it could be presented, because our schema for this type of algebra problem informs us, for example, that the solution requires multiplying out the denominator on the left-hand side, irrespective of the complexity of the term on the right-hand side. Schemas, stored in long-term memory, permit us to ignore the variety that would otherwise overwhelm our working memory.

Automation (Kotovsky, Hayes, & Simon, 1985; Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977) allows cognitive processes to occur without conscious control. With time and practice, all cognitive processes can occur automatically. For example, when we first acquire a schema for the problem, $a/b = c$, solve for a, we may need to consciously consider the problem before realizing that it belongs to the category that requires multiplying out the denominator as the first move. After considerable practice, the schema will become automated, and we will instantly recognize the category of problem facing us. Automatic recognition allows us to bypass working memory. The material is processed with minimal demands on our limited processing capacity, and this may be the primary function of automation.

In summary, when dealing with higher intellectual activities, our cognitive system consists essentially of a powerful long-term memory, a limited working memory, and the learning mechanisms, schema acquisition and automation, that use material stored in long-term memory to reduce the burden on working memory. This integrated system provides a basic architecture used to generate the theorizing and empirical work that follow. We begin by considering an essential factor that makes some material difficult to learn, irrespective of the form in which it is presented.

ELEMENT INTERACTIVITY AS AN INTRINSIC SOURCE OF COGNITIVE LOAD

It is proposed that the cognitive load associated with material to be learned is strongly related to the extent to which the elements of that material interact with each other. Consider the task of learning the nouns of a second language. If we concentrate entirely on vocabulary and not syntax, it can be seen that many words can be learned without reference to other words: The elements of the task have virtually zero interactivity. The second language translation of the word *cat* can be learned without learning the translation of the word *dog* or, indeed, any other word. Each translation can be learned individually, in isolation.

In learning a language, we not only must learn a vocabulary but also must assimilate the syntax of the language. A huge variety of factors are likely to be important in this task, among them, in English, the order that is appropriate for words. When learning the conditions under which a particular word order is appropriate, it may well be the case that both the syntactic and semantic characteristics of each word in relation to each of the other words must be taken into consideration. The elements of the task cannot be learned in isolation because they interact with each other. In English, we cannot sensibly learn how to use the verb *to be* without simultaneously learning an entire complex of syntactic and semantic relations.

The cognitive load associated with learning some vocabulary is low because the elements of the material to be learned do not interact with each other. Each word is an element, and because it can be learned in isolation from other elements, the cognitive load imposed by any individual element is likely to be well within our processing capacity. It should be noted that the task is difficult not because it is difficult to assimilate each element but because a huge number of elements must be assimilated. The task does not tax our limited processing capacity; rather, it taxes our ability to assimilate large amounts of information into long-term memory over relatively short periods.

When acquiring language syntax, the elements of information that must be learned may be difficult to assimilate, because they cannot be acquired in isolation. In this case, elements may be the syntactic and semantic relations of each word to every other word. Each element must be learned in conjunction with several other elements, because they have a high degree of interactivity. The interactions between the various elements may provide the whole point of what must be learned. For this reason, the elements may be very difficult to assimilate.

Under these circumstances, learning difficulty is not just a function of the number of elements that must be learned but also a function of the number of elements that must be learned simultaneously. Complexes of elements that are irreducibly large because they consist of many connecting elements may tax our limited processing capacity and so impose a heavy cognitive load. Our limited processing capacity may provide an effective bar to assimilating the material, even if the total amount of material is small.

The different subject matters that people need to learn vary dramatically in the degree of interactivity of their elements. Some areas may consist almost entirely of heavily interacting elements that impose a heavy cognitive load. Other areas, at the other end of the continuum, may have many elements, but those elements may have low degrees of interactivity, resulting in a limited cognitive load. If an area with low levels of element interactivity is difficult to learn, it is because of the total number of elements that must be assimilated, not the number that must be assimilated simultaneously. Consider the following example of high interactivity between the elements of a simple algebra task.

A student learning elementary algebra must learn how to multiply out the denominator of one side of an equation in order to isolate a single pronumeral in the numerator on that side. The student needs to learn what to do when faced with an equation such as the one previously discussed: $a/b = c$, solve for a. To learn this process, the student must learn that, when multiplying by b, the numerator on the left-hand side is multiplied by b, giving ab; the two bs on the left-hand side cancel out, leaving a isolated; because the left-hand side has been multiplied by b, the right-hand side must also be multiplied by b; multiplying the right-hand side by b gives cb in the numerator on the right-hand side; the denominator remains unchanged at 1, which is not shown in the equation; the net consequence is $a = cb$, which meets the goal of isolating the numerator on the left-hand side of the equation.

Each of these steps can be considered an element in the total unit of learning to multiply out a denominator. None of these elements in isolation is likely to be seen as being particularly difficult by algebra students. The difficulty is that they cannot be learned in isolation, because, alone, none of them makes mathematical sense. To understand how to multiply out a denominator, one must learn each of these elements simultaneously, because they all interact. The elements constitute a single, large, indivisible unit that must be assimilated as a whole, rather than in small parts over time. This part of a curriculum has a high degree of interactivity, the cognitive load imposed is large, and many members of a population may have extreme difficulty dealing with so many elements simultaneously.

It should be noted that there is some evidence for the importance of element interactivity as a source of cognitive load. Halford, Maybery, and Bain (1986) and Maybery, Bain, and Halford (1986), using transitive inference problems, found the heaviest cognitive load to be at the point where element interactivity was at its greatest.

Relations to Schema Theory

When dealing with information consisting of many interacting elements, we are dealing with a schema. There may be no useful distinctions that can be made between interacting elements and schemas. Furthermore, elements are essentially lower-order schemas. When learning to read, we must acquire schemas to enable us to recognize the letters of the alphabet that can occur in an infinite variety of forms (e.g., handwriting). These lower-order schemas then become the elements that make up words for which new, higher-order schemas must be acquired. These schemas then act as elements in phrases and sentences. In a similar vein, acquiring a schema for multiplying out a denominator requires a learner to assimilate the interacting elements described earlier. Once this schema has been acquired, it may be used as an element in more complex mathematics, leading to higher-order schemas. In summary, what constitutes an element cannot be determined simply by analyzing the information. A single element for one person with a sophisticated schema may be many interacting elements for others. Learning through schema acquisition reduces cognitive load by reducing the number of interacting elements with which working memory must deal.

Measuring Element Interactivity

The extent to which elements interact for any given information can be estimated by counting the number of elements that must be considered simultaneously in order to learn a particular procedure. As indicated in the previous section, what constitutes an element is determined by the expertise of the individual who is learning the material. Just as working memory theorists must assume what constitutes a *chunk* before estimating the capacity of short-term memory, because a chunk for one person may be several dozen elements for another, so we assume that a person learning new material is familiar with some but not all of the constituent parts or elements and their interactions. In the next example, we assume that the knowledge levels of the relevant learner is such that each of the elements listed and their interactions must be learned. Once the interactions have been learned, a new schema that can act as a single element has been acquired, and element interactivity is no longer relevant.

Assume a person is learning how to specify a point on a coordinate system. In effect, the person is learning how to translate algebraic notation, such as $P(x, y)$, into two-dimensional space and vice versa. The following provides an estimate of the elements that must be learned simultaneously to accomplish this task:

1. The x axis is a graduated, horizontal line; the y axis is a graduated, vertical line. These two lines cross at the zero point on both axes, called the origin, and are at right angles because one is vertical and the other horizontal.

2. P in $P(x, y)$ refers to the relevant point in both the algebraic and geometric systems.
3. x in $P(x, y)$ refers to a location x on the x axis.
4. y in $P(x, y)$ refers to a location y on the y axis.
5. Draw a line from x on the x axis at right angles to the axis.
6. Draw a line from y on the y axis at right angles to the axis.
7. The point where these two lines meet is $P(x, y)$.

To locate a point on a two-dimensional, coordinate system, these seven elements must be considered simultaneously. The seventh element only makes sense in conjunction with the other elements. In isolation, the element is trivially simple, but it is not possible to assimilate that element without assimilating the others. A similar division of information into constituent elements (or the chunks of working memory researchers) can be carried out for any material.

Although the number of elements that must be considered simultaneously in the preceding example is seven, it must be reemphasized that this number is only an estimate based on the assumed knowledge of the learner. For most readers of this article, the entire example is likely to be incorporated into a single element, because an appropriate, automated schema was acquired long ago. Locating $P(x, y)$ probably can be carried out with minimal conscious thought or perhaps even while engaged in alternate cognitive activities. In contrast to people for whom the entire set of elements just listed have been concatenated into a single element, for others the seven elements may need to be expanded. As an example, Element 1 is assumed to be a single element, because most students studying coordinate geometry for the first time are likely to be familiar with vertical and horizontal lines and are aware that such lines are at right angles to each other. For a person who does not have an appropriate automated schema, Element 1 will need to be divided into multiple elements with a consequent increase in the total number.

From this analysis, it can be seen that the number of interacting elements that must be learned is necessarily an estimate. In all cases in the experiments that follow, where comparisons were made between high and low element interactivity, materials were chosen in which the differences in element interactivity were sufficiently large to ensure that any errors in estimation were likely to be trivial in comparison with the differences.

INSTRUCTIONAL FORMAT AS AN ARTIFICIAL SOURCE OF COGNITIVE LOAD

The preceding discussion has been concerned with intrinsic cognitive load determined by the nature of the materials. All information that must be assimilated falls somewhere on a continuum ranging from a limited number of elements with limited interactivity to many elements with high interactivity. The difficulty of an area is determined by both the number of elements that must be learned and the extent to which they interact. The cognitive load imposed by the intrinsic nature of the material is determined solely by element interactivity, not by the total number of elements that must be assimilated. Information may be difficult to learn because it consists of many elements, but may impose a low cognitive load because the elements do not interact greatly. High element interactivity results in a high cognitive load, even if the total number of elements is small. Nevertheless, high element interactivity due to the intrinsic nature of the information is not the only source of cognitive load. High levels of element interactivity and its associated cognitive load can be induced by instructional designs.

Cognitive load theory (Sweller, 1988, 1989, 1993) suggests that the severe limitations of the human information-processing system discussed earlier have consequences for the design and presentation of instructional material. Although our processing limitations have been well known for a very long time, our instructional designs and techniques have tended to develop with little or no reference to this basic fact of our mental life. Until recently, it has been rare to find a discussion of the cognitive load implications of either traditional or newly recommended instructional procedures (see Paas, 1992, for a recent discussion). As a consequence, many commonly used instructional techniques unnecessarily result in a high degree of element interactivity and so impose a heavy extraneous cognitive load that interferes with learning. An extraneous cognitive load is one that is imposed purely because of the design and organization of the learning materials rather than the intrinsic nature of the task. Learners must engage in irrelevant cognitive activities involving the simultaneous manipulation of elements solely because of the manner in which the task is organized. An irrelevant cognitive activity is any activity not directed to schema acquisition and automation. A more appropriate organization, by eliminating irrelevant cognitive activities, should reduce extraneous cognitive load and thus facilitate learning. Sweller and Chandler (1991) summarized several effects that have given rise to techniques designed to reduce extraneous cognitive load and for which there is empirical evidence of effectiveness. Two are of concern in the present article: the split-attention and redundancy effects.

The Split-Attention Effect

Demonstrations of the negative consequences of split attention may be found in Chandler and Sweller (1991, 1992); Sweller, Chandler, Tierney, and Cooper (1990); Tarmizi and Sweller (1988); and Ward and Sweller (1990). Instructional material frequently and unnecessarily requires students to split their attention among and mentally integrate multiple sources of information. For example, geometry instruction routinely requires students to attend to a diagram and to associated statements. Neither the diagram nor the statements are intelligible until after they have been mentally integrated. The act of mental integration involves finding relations among elements associated with the diagram and statements. Unless the relevant interactions among the elements are found, the instruction will be unintelligible. Finding relations among disparate elements requires cognitive resources that must be expended purely because of the normal way in which geometry instruction is formatted. There is no requirement, intrinsic to the subject matter, to keep the diagram and statements separate. A consequence of the separation is that an extraneous cognitive load is imposed. Physical integration of the statements and diagram, by, for example, inserting statements in an appropriate location on the diagram and so incorporating two or more elements into a single element, reduces extraneous cognitive load and enhances learning. Related results have been obtained by Mayer and Anderson (1992), who found that contiguous presentation of oral and visual information was superior to successive presentation.

The Redundancy Effect

Chandler and Sweller (1991) found that learning was enhanced by the elimination of textual material that described the contents of a diagram. They labeled the phenomenon the *redundancy effect*. Unlike the split-attention effect, which deals with segments of information that are unintelligible until physically or mentally integrated, the redundancy effect deals with segments of information that can be understood in isolation. By adding redundant elements such as text, students may associate those elements with the essential diagram, increasing element interactivity. Furthermore, physical integration unnecessarily forces students to attend to the redundant information. Rather than simply considering the diagramatic information, students are forced to consider both diagrammatic and textual information and the relations between them. The increase in element interactivity results in physical integration having negative rather than positive effects. The elimination, rather than integration, of redundant material enhances learning. Chandler and Sweller suggested that attention to redundant material imposes an extraneous cognitive load that interferes with the learning of core material.

Note that the redundancy effect seems to have been discovered and rediscovered in different contexts on many occasions over many years: W. Miller (1937) using young children learning to read nouns associated with redundant pictures (see Saunders & Solman, 1984, for more recent work); Reder and Anderson (1980, 1982) comparing the consequences of reading textbook chapter summaries rather than entire chapters; Lesh, Landau, and Hamilton (1983) observing the effects of solving mathematical word problems with the presence or absence of redundant concrete materials; and Schooler and Engstler-Schooler (1990) investigating the effects of having to verbalize visual stimuli. All found that redundant materials or activities, rather than having the beneficial effect assumed by many people, impaired performance. Different explanations have been offered for all of these findings. Because they all used a basic paradigm in which additional, redundant information was found to interfere with core information, they all may be examples of the same effect and explainable in cognitive load terms.

COGNITIVE LOAD CONSEQUENCES OF RELATIONS BETWEEN ELEMENT INTERACTIVITY AND INSTRUCTIONAL DESIGN

To process materials that consist of elements with an intrinsically high degree of interactivity requires substantial cognitive resources. The heavy cognitive load imposed by such materials is not, of course, extraneous. It is an essential part of assimilating and learning the material. Nevertheless, because of the heavy cognitive load imposed by such materials, they are likely to be particularly susceptible to any extraneous cognitive load imposed by the manner of presentation. A heavy cognitive load imposed by a combination of high intrinsic element interactivity and inappropriate presentation techniques causing high extraneous element interactivity may be overwhelming. In contrast, if the information that we require students to assimilate consists of relatively little or no intrinsic element interactivity, presentation techniques that impose a heavy extraneous cognitive load may not matter as much. Sufficient cognitive capacity may be available to assimilate the information under a very wide variety of presentation techniques. The consequences of extraneous cognitive load may be important only when dealing with material that has a high level of intrinsic element interactivity.

The split-attention and redundancy effects described earlier were investigated using materials that incidentally incorporated elements with high levels of intrinsic interactivity. There now are clear theoretical grounds for hypothesizing that the effects will be reduced or eliminated using materials with lower levels of intrinsic interactivity among their elements. Materials that consist of single, noninteracting elements, for example, may not permit us to demonstrate any of the effects generated by cognitive load theory. This article is concerned with investigating that possibility with respect to the split-attention and redundancy effects.

Cognitive load theory, used to generate the experiments of this article, can be summarized as follows: The learning mechanisms, schema acquisition and automation, reduce the burden on working memory by emphasizing long-term memory. Acquiring some schemas imposes a heavy intrinsic cognitive load, because their elements cannot be meaningfully assimilated in isolation due to interaction among them. Some instructional designs also require learners to simultaneously assimilate multiple elements of information and so impose a heavy extraneous cognitive load. When dealing with material with intrinsically high element interactivity, an instructional design that reduces unnecessary element interactivity and its associated extraneous cognitive load is critical.

LEARNING TO USE EQUIPMENT

Relations between intrinsic cognitive load due to high intrinsic element interactivity and extraneous cognitive load due to instructional format are considered using learning tasks associated with hardware and software. As indicated earlier, the split-attention and redundancy effects can provide the basis for varying instructional format.

Consider a person who must learn to use a new computer program. Probably the most common procedure is to begin by referring to the relevant manual. The instructions in the manual require use of the keyboard and attention to information on the screen. In most cases, neither the manual nor the screen information is likely to be intelligible to the novice until both sources of information have been mentally integrated. As a consequence, we have a classic split-attention situation, with learning impossible until the elements of the manual and computer have been integrated. To learn the new computer application, students must split their attention among and mentally integrate information from the manual, screen, and keyboard. We might expect cognitive load to be reduced by an appropriate form of physical integration that obviates the need for mental integration.

How could we physically integrate a manual and a computer screen? One way is to eliminate the manual and place everything on the screen using a form of computer-assisted instruction. There has been an explosion of interest in computer-assisted instruction over the last few years, and a final verdict on the techniques used is not yet in. An alternative, apparently bizarre but nevertheless theoretically driven approach would be to eliminate the computer rather than the manual and place all information, including, where necessary, diagrams of screen information and keyboards, in a manual. In this way, if properly organized, manual, screen, and keyboard information can be physically integrated and the computer dispensed with until learning is well under way. Extraneous cognitive load should be reduced, and the split-attention effect should be obtainable by comparing this modified-manual-only group with a conventional-manual-plus-computer group. The manual of this conventional group can refer learners to the screen or the keyboard in the conventional manner rather than have pictures representing the screen and keyboard.

Given the previous theorizing, this effect should be obtainable only if the computer application that must be learned has a high degree of intrinsic element interactivity. If, as happens with respect to some applications, each element can be learned independently of other elements, we would not expect the split-attention effect. A modified-manual-only group may be no better or may be worse than a conventional-manual-plus-computer group.

Rather than comparing a modified-manual-only group with a conventional-manual-plus-computer group, we could compare a modified-manual-only group with a group given access to a computer and the integrated pictures-and-text (i.e., modified) manual. This modified-manual-plus-computer group would differ from the conventional-manual-plus-computer group in that the integrated rather than the conventional manual is used. A conventional manual is not intelligible without a computer, because the learner must see what is on the screen and keyboard before the manual can be followed, whereas the modified manual is intelligible alone. When the modified manual is used, the computer is redundant. Thus, a comparison of a modified-manual-plus-computer group with a modified-manual-only group could yield the redundancy effect. The additional elements associated with the computer will interact with the manual (unless students ignore the computer), and the extraneous cognitive load imposed by attending to the computer may interfere with learning. Again, this redundancy effect should be obtainable only with high intrinsic element interactivity materials that naturally impose a heavy cognitive load.

In summary, if we compare a modified-manual-only group with a conventional-manual-plus-computer group, we have a split-attention effect experiment and can predict that the cognitive load imposed by the requirement to split attention between a manual and the computer should result in a performance decrement compared with a modified-manual-only group. If we compare a modified-manual-only group with a modified-manual-plus-computer group, we have a redundancy effect experiment and can predict that the cognitive load imposed by the need to process information associated with redundant equipment should result in a performance decrement compared with a modified-manual-only group. In both cases, whether the modified-manual-only group is superior should depend on the extent to which the information learners are attempting to assimilate has a high or low degree of intrinsic element interactivity. The effects should only be obtainable with high levels of intrinsic element interactivity. The remainder of this article tests these hypotheses.

EXPERIMENT 1

This experiment was designed to compare a conventional-manual-plus-computer group with a modified-manual-only group using an instructional package with a high degree of intrinsic element interactivity. The conventional-manual-plus-computer group required learners to split their attention among the manual, screen, and keyboard. The modified manual was identical to the conventional version except that, wherever the conventional manual required learners to look at the screen or keyboard, the modified manual had illustrations physically integrated with the text.

The package used was a computer-aided design/computer-aided manufacture (CAD/CAM) program designed for the control of industrial machinery. To use a CAD/CAM system, one must learn to use a coordinate system to enable location and movement of objects (see Chandler, Waldron, & Hesketh, 1988, or Hesketh, Chandler, & Andrews, 1988). This system, in common with most or possibly all coordinate systems, has a high degree of intrinsic element interactivity. Much of the coordinate system must be learned as a single, large unit. It is difficult to learn how a small part of the system works before progressing to the next small part. Rather, the entire system needs to be learned and understood before any of it can be used.

For a simple example, assume that one is learning how to move the position of an object in two-dimensional space using the coordinate system. To do this, one must simultaneously consider how the horizontal and vertical axes are represented, the rules for locating position on each of these axes, and the rules for indicating a change in position on each axis. Section A of Appendix A provides an estimate of the number of interacting elements needed to learn this aspect of the CAD/CAM system used in Experiment 1. All 10 elements must be considered when the system is used to move the position of an object. Although some of the rules can be learned individually without reference to the others, the simple task of moving an object requires not only that all be used simultaneously but also the relations and interactions among all entities be considered simultaneously. Until an automated schema has been acquired that permits these rules and processes to be treated as a single element, the cognitive load imposed may exceed available capacity.

The elements listed in section A of Appendix A assume that certain schemas have already been acquired. For example, we indicated earlier the seven elements required to locate a point on a coordinate system. The elements of section A of Appendix A assume that learners already have acquired this skill; therefore, the seven elements are incorporated in other, higher-order elements. If a schema for locating a point on a two-dimensional coordinate system has not been acquired, the number of elements in section A of Appendix A would need to be much larger.

In contrast to the relatively large number of interacting elements that must be learned to change the position of an object, far fewer interacting elements must be learned to affect unidimensional movement (section B of Appendix A) or to draw a line (section C of Appendix A). In these cases, little more than the function of individual keys needs to be learned, and these functions can be learned independently of each other. Element interactivity is low.

We predicted that a split-attention effect would be demonstrated with the high element interactivity materials. Because some CAD/CAM instructions consist of elements with an intrinsically high degree of interactivity that require considerable cognitive effort to process, the presentation technique becomes critical. We can hypothesize that the added burden of the extraneous cognitive load imposed by the conventional-manual-plus-computer format would disadvantage learners when compared with a modified-manual format designed to eliminate split-attention and reduce extraneous cognitive load. It should be noted that this disadvantage should only apply to those aspects of the materials that involve high element interactivity. Aspects of the information involving low element interactivity should not be as strongly affected by instructional procedure.

Method

Subjects. The subjects were 20 first-year trade apprentices from a Sydney company. All subjects had completed at least Year 10 of high school and were enrolled in first-year trade courses at various technical colleges. All 20 subjects had previous experience with computers at high school. Because the instructional package was designed as an introduction to CAD/CAM systems, only apprentices with no previous exposure to CAD/CAM programs were used.

Materials. The instructional materials for the experiment consisted of two sets of manual instructions (conventional and modified) designed to introduce learners to CAD/CAM systems. Both sets of instructions were divided into four sections: (a) introduction to CAD/CAM, (b) moving the cursor in different size steps, (c) drawing lines, and (d) drawing new lines.

The conventional instructions consisted of textual information taken directly from the manual of a widely used CAD/CAM package. Only limited revisions were made to the instructions in the interest of clarifying minor ambiguities. The conventional-manual instructions were unintelligible by themselves and were designed to be used in conjunction with the software installed on the computer. The modified instructions contained textual information virtually identical to the conventional instructions but also included diagrams of the computer screen and the computer keyboard. Related textual information and diagrammatic information were physically integrated into unitary sources of information. An example of the modified-manual instructions is shown in Figure 1.

The test materials consisted of a small test booklet, as well as the hardware and software for practical tests. The test booklet was divided into four problems covering all four sections of the instructional materials. For the first problem, learners were presented with a diagram of the computer screen and keyboard and were required to locate five keys on the keyboard and two entities on the computer screen. One mark was allocated for each correct location, giving a total mark out of seven. This problem tests information that has low element interactivity. Students could learn the name and function of a particular key, for example, the return key, without knowing anything about other keys such as the space bar.

Problem 2 was divided into six parts. Each part requested learners to provide the steps involved in moving the screen cursor a particular distance in a particular direction. For example, one part asked learners to write down the steps involved in moving the cursor 25.2 mm to the left. One mark was given for each correct part, giving a total score out of 6. This problem again tested low element interactivity material. To answer the problem, subjects had to learn how to move the cursor a specified distance and how to move it up, down, left, or right. When moving the cursor 25.2 mm, different steps are involved in moving 20, 5, and .2 mm, respectively. Each of these steps is a single element that can be learned independently of all the others, resulting in low element interactivity. Section B of Appendix A provides an estimate of the required elements.

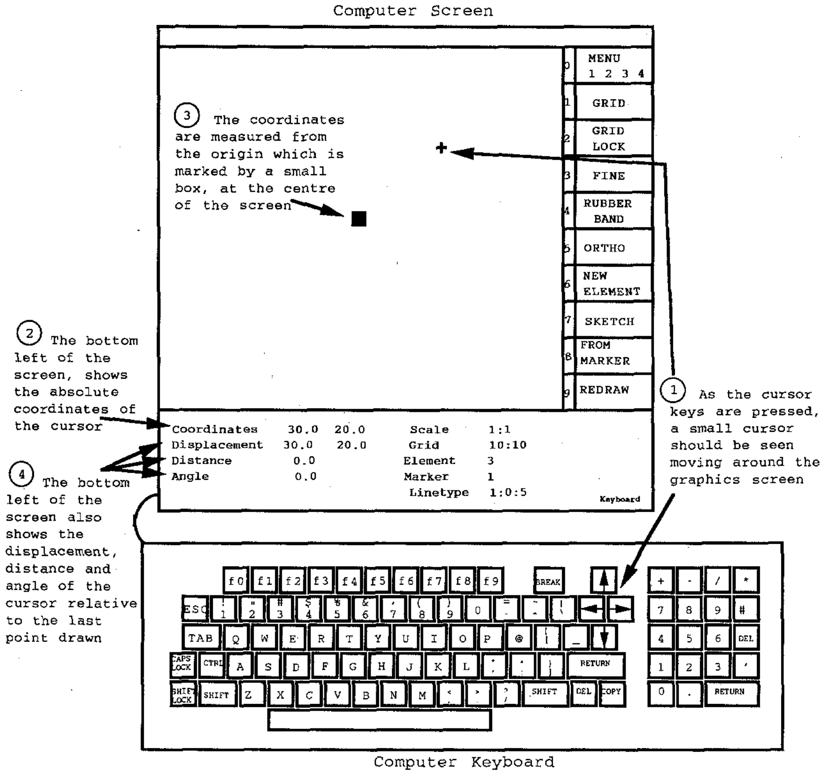


FIGURE 1 An example of the modified-manual instructions used in Experiment 1.

The third problem asked learners to provide the two steps involved in drawing a line from the origin to the absolute coordinate position of (40.0, 50.0). The two steps are moving the cursor and pressing the return key. One mark was given for each correct step, giving a total mark out of 2. The first step has high element interactivity as indicated in section A of Appendix A. To learn this step, students must simultaneously keep in mind the two sets of coordinates with four coordinate positions, the relations between them, and the relations between those relations and the procedures for drawing a line. Learning to move the cursor involves processing the relations among all these elements simultaneously. They cannot be processed in isolation. If an automated *move the cursor* schema has not been acquired, simultaneous processing of these elements may overburden working memory. The second step of the third problem required pressing the return key and could be learned independently of the first step. It has low element interactivity, as indicated in section C of Appendix A.

Problem 4 requested learners to give the four steps involved in drawing a line from the absolute coordinate position of (–10.0, 20.0) to the absolute coordinate position of (10.0, 30.0). As with Problem 3, one mark was allocated for each correct step, giving a total mark out of 4. The four steps were: Find the first coordinate, press the space bar, find the second coordinate, and press the return key. Pressing individual keys can be learned serially and is a low element interactivity task. As was the case for the first step of the third problem, finding a coordinate requires an understanding of coordinate systems and that requires learning the relation between the horizontal and vertical coordinates. Again, as indicated in section A of Appendix A, the elements of the horizontal and vertical coordinates must be considered simultaneously in order to understand the relation between them and to find a coordinate position, resulting in a high level of element interactivity.

The practical test was conducted with the software loaded on the computer. The test, requiring learners to draw a number of lines, consisted of six parts: (a) Move to the absolute coordinate position of (31.1, 31.1), (b) draw a line from the origin to the absolute coordinate position of (31.1, 31.1), (c) go to the absolute coordinate position of (40.0, 40.0), (d) draw a line from the absolute coordinate position of (31.1, 31.1) to the absolute coordinate position of (40.0, 40.0), (e) go to point (50.0, 0.00), and (f) draw a line from the absolute coordinate position of (50.0, 0.00) to the absolute coordinate position of (31.1, 31.1). One mark was given for correctly performing each part of the test, giving a practical test score out of 6. The first, third, and fifth parts each involve high element interactivity, because they require students to locate particular coordinate positions for which they must have learned the essential characteristics of the coordinate system (see section A of Appendix A). To answer the second, fourth, and sixth problems, students must learn to press individual keys at particular times (see section C of Appendix A). This information is intrinsically low in element interactivity.

Procedure. The experiment was conducted in two phases. The first phase was the instructional phase. Learners were randomly assigned to either a conventional-manual-plus-computer group or a modified-manual-only group. All learners were tested individually. Learners in the conventional-manual-plus-computer group were informed that they would be given some introductory CAD/CAM instructional material to perform on the computer, followed by both a written and practical test. They were then seated in front of the computer. The experimenter familiarized the subject with the layout of the keyboard and the computer screen and asked if there were any questions. The learners were also informed that they were free to ask questions throughout the instructional phase. The experimenter monitored the learner during the instructional phase to ensure that the learner was continually interacting with the computer. If the learner failed to press a key in a 45 sec period, the experimenter asked if there was a problem and answered any queries to the learner's satisfaction. Learners in the modified-manual-only group were given their instructions and also informed that they would be required to perform a written and practical test at the completion of the instructional phase. Learners in this group had no contact with the computer and were simply asked to study the instructions. Both groups were asked to indicate when they were finished with the instructional material. Time to completion was recorded.

The test phase, common to both groups, followed. Instructional materials were not available to learners during testing. First, learners were required to attempt the written test described in the Materials section. There was no time limit on the test. A problem could not be reattempted after it had been answered. The practical test followed. Learners were required to attempt each of the six parts of the practical test with one part given at a time and up to 2 min to complete each part. If the learner failed to complete the task successfully in this time period, the experimenter showed the solution, and the learners attempted the next part of the test. Time to completion was noted for both the written and practical tests.

Results and Discussion

The variables under analysis were instruction time, written and practical test time, and written and practical test score. Means and standard deviations for these variables are displayed in Table 1. Possible differences between the two groups were assessed through *t* tests. Results indicated the modified-manual-only group spent significantly less time studying their instructions than the conventional-manual-plus-computer group, $t(18) = 3.87$ (a significance level of .05 is used throughout this article unless otherwise stated). This result is not surprising, considering that the conventional-manual-plus-computer group was required to interact continually with the computer, whereas the modified-manual-only group simply had to study their manual. Of far more importance was whether differential instructional treatments had consequences during the test phase.

One-tailed *t* tests indicated that the modified-manual-only group spent significantly less time than the conventional-manual-plus-computer group completing both the written test, $t(18) = 1.92$, and the practical test, $t(18) = 1.98$. These analyses are based on time to completion, including incorrect solutions, not time to correct solution. As will be shown later, the written and practical test scores also favored the modified-manual-only group when dealing with high interactivity materials.

All 20 learners achieved a perfect score of 7 for the first problem. This result indicated that all learners, including those in the modified-manual-only group who had not had prior exposure to the actual equipment, had no difficulty in locating important keys on the keyboard and entities on the screen. The material covered by this problem not only involved low element interactivity information but also was low in total information content.

There was no significance difference between the groups on the second test problem, $t(18) = 0.64$. An inspection of Table 1 means indicates that this lack

TABLE 1
Instruction Times, Test Times, and Test Scores of Experiment 1

Group	*Instruction Time (sec)*	*Written Test Time (sec)*	*Practical Test Time (sec)*	*Written Test Problem Scores*				*Practical Task Scores*
				1	*2*	*3*	*4*	
Conventional-manual-plus-computer								
M	240.5	529.0	383.4	7	3.7	1.1	1.7	4.0
SD	50.1	149.7	176.4	0	2.1	0.7	1.5	1.6
Modified-manual-only								
M	166.4	410.1	258.6	7	4.2	1.9	3.0	5.3
SD	34.1	126.6	92.9	0	1.4	0.3	0.9	0.8

of a significant effect on the second problem was not due to a ceiling effect, as was the case for the first problem. Students made many errors, indicating that the total information content was high. Nevertheless, cognitive load due to high element interactivity was absent on the materials that needed to be learned to answer this problem. For these low element interactivity materials, instructional format proved to be unimportant.

Results showed that the modified-manual-only group scored significantly higher than the conventional-manual-plus-computer group on both Problem 3, $t(18) = 3.15$, and Problem 4, $t(18) = 2.33$. Both of these problems contained steps based on high, intrinsic element interactivity materials. We consider the results obtained on the individual steps of these problems in more detail later. The difference between the groups on Problem 3 was contributed to more heavily by the first step, which required knowledge of the coordinate system with its high element interactivity, than the second step, which relied on knowledge that was low in element interactivity. Table 2 indicates the number of subjects who were correct on each step. On Problem 4, the first and third steps relied on high element interactivity, coordinate system knowledge, whereas the second and fourth steps tested low element interactivity knowledge. Table 2 indicates the number of students who were correct on each of these steps. As can be seen from these results, in all cases, the difference between the groups was greater when students had to rely on high element interactivity materials to answer the problem. In fact, for Problems 3 and 4, there was a significant difference between groups on the three steps requiring high element interactivity knowledge but no significant difference on the three steps involving low element interactivity knowledge using Fisher Exact Probability Tests with Overall's (1980) correction. (All Fisher Exact Tests in this article used Overall's correction.) We can conclude that differences between the two groups on Problems 3 and 4 were contributed to more heavily by high than low element interactivity materials.

A difference between the groups was also found on the practical test with the modified-manual-only group outperforming the conventional-manual-plus-computer group, $t(18) = 2.32$. This is an impressive result, considering that the conventional-manual-plus-computer group had considerable exposure to the

TABLE 2
Number of Subjects Successfully Completing the Individual Steps of Problems 3 and 4 of the Written Test for Experiment 1

		Problem 3 Step		*Problem 4 Step*			
Group	*n*	*1*[a]	*2*[b]	*1*[a]	*2*[b]	*3*[a]	*4*[b]
Conventional-manual-plus-computer	10	5	6	5	3	4	5
Modified-manual-only	10	10	9	10	4	8	8

[a]High element interactivity. [b]Low element interactivity.

computer during the instructional phase. The modified-manual-only group still demonstrated its superiority, despite having no prior exposure to the CAD/CAM package in actual operation on the computer. The superiority of the modified-manual-only group was due entirely to the first, third, and fifth parts of the practical test (see Table 3). These parts required students to find coordinate positions and so involved high element interactivity. The differences between the two groups in number of students correct on each part was significant, using Fisher Exact Tests. There were no equivalent significant differences on the second, fourth, and sixth parts, which involved pressing single keys, and were low in element interactivity. It must be noted, of course, that, with the exception of the sixth part, the lack of difference was due to ceiling effects.

The overall results of this experiment clearly favored the modified-manual-only group. Despite spending less time studying their instructions, the modified-manual-only group was superior to the conventional-manual-plus-computer group in both written and practical test skills. Importantly, the superiority of the modified-manual-only group was very specific to particular parts of particular problems. It occurred only on those sections of the material that dealt with information closely associated with the coordinate system and that, as a consequence, was high in element interactivity. We believe that these results are best explained by reference to the extraneous cognitive load imposed by conventional instructional formats. Because much of the knowledge associated with CAD/CAM instructions has a high level of element interactivity, which we have suggested imposes an intrinsically heavy cognitive load, any excessive extraneous cognitive load may further hinder learning. We suggest that the conventional instructional format provides this excessive cognitive load. The learner is faced with the task of mentally integrating information from a manual with a computer screen and computer keyboard while learning the fundamentals of CAD/CAM systems. The modified-manual instructions reduce this extraneous cognitive load by providing a format where disparate sources of information are physically integrated. This reduction in extraneous cognitive load is especially important when dealing with material that has a high level of intrinsic element interactivity, such as learning a coordinate system. The fact that the modified-manual-only group had no exposure to the computer during

TABLE 3
Number of Subjects Successfully Completing the Individual Steps of the Practical Task of Experiment 1

		Practical Task Step					
Group	*n*	*1*[a]	*2*[b]	*3*[a]	*4*[b]	*5*[a]	*6*[b]
Conventional-manual-plus-computer	10	4	10	5	9	6	6
Modified-manual-only	10	9	10	10	8	10	6

[a]High element interactivity. [b]Low element interactivity.

the instructional phase was overwhelmed by these factors and proved to be an advantage, rather than a handicap.

Although the results of Experiment 1 strongly favored the modified-manual-only group and thus supported the hypothesis that access to the computer interfered with learning, it could be argued that the results were due simply to the modified manual being superior to the conventional manual. The plausibility of this argument is reduced by the fact that both manuals were essentially identical, except that the modified manual had diagrams to replace the actual equipment. Nevertheless, it is desirable to eliminate this possibility through experimental manipulation. If two groups use the modified manual but only one group has access to the equipment, differences can only be attributed to the presence of the equipment. Such a comparison, which tests for the redundancy effect because the equipment is redundant, was incorporated into Experiment 2.

EXPERIMENT 2

The results of Experiment 1 demonstrated a split-attention effect using materials with a high degree of interaction between individual elements. As indicated in the introduction, cognitive load theory also predicts the redundancy effect. It might be anticipated that a similar pattern of results is obtainable when testing for the redundancy effect as was obtained in Experiment 1 for the split-attention effect. We have suggested that the nature of the instructional material dictates the extent to which the presentation format plays a role in learning. Presentation formats designed to reduce extraneous cognitive load are more important when dealing with instructions with a high, rather than a low, level of element interactivity. Experiment 1 found the split-attention effect only when dealing with high element interactivity material. It is reasonable to hypothesize, similarly, that the redundancy effect will be obtainable more readily using high rather than low element interactivity material. Experiment 2 was designed to replicate the split-attention results of Experiment 1 using different materials and subjects, as well as to extend and generalize the findings by testing for the redundancy effect.

As was indicated in Experiment 1, instructional materials often contain sections with a low level of element interactivity and other sections with a high level of element interactivity. Modern spreadsheets are one such example. Spreadsheets are generally divided into cells in which data can be entered, displayed, and manipulated. Typing data into a spreadsheet, moving through a spreadsheet, deleting, replacing, and inserting data are low interactive tasks (see sections C and D of Appendix B). There is little element interactivity because individual elements can be learned independently. Conversely, tasks such as performing functions on a spreadsheet involve high levels of element interactivity. Functions are codes that stand for a special formula that operates on data entered into the spreadsheet. To understand a function code, one must first learn that the spreadsheet is divided into many cells, with each cell representing the intersection of a particular row and column. Data occupying these cells can be manipulated through function codes. All function codes are unintelligible unless the learner has an understanding of the layout of the spreadsheet. In addition, the function code or formula itself consists of multiple elements, none of which can be understood or learned other than in conjunction with the other elements. A high degree of element interactivity is a consequence (see sections A and B of Appendix B).

When dealing with a spreadsheet, we can predict that problems concerned with high element interactivity materials will generate the split-attention and redundancy effects, whereas low element interactivity materials will not. Thus, the presence or absence of the effects should depend on what aspect of the spreadsheet is being tested.

There were three groups in Experiment 2. The two instructional formats of Experiment 1 were retained, namely, a conventional-manual-plus-computer and a modified-manual-only format. A third group, working with a modified manual while interacting with the computer, was added to the experiment. This modified-manual-plus-computer format involves an extraneous cognitive load, because learners are required to perform the instructions on the computer while studying a self-contained modified manual. Comparing this group with a modified-manual-only group provides a test of the redundancy effect.

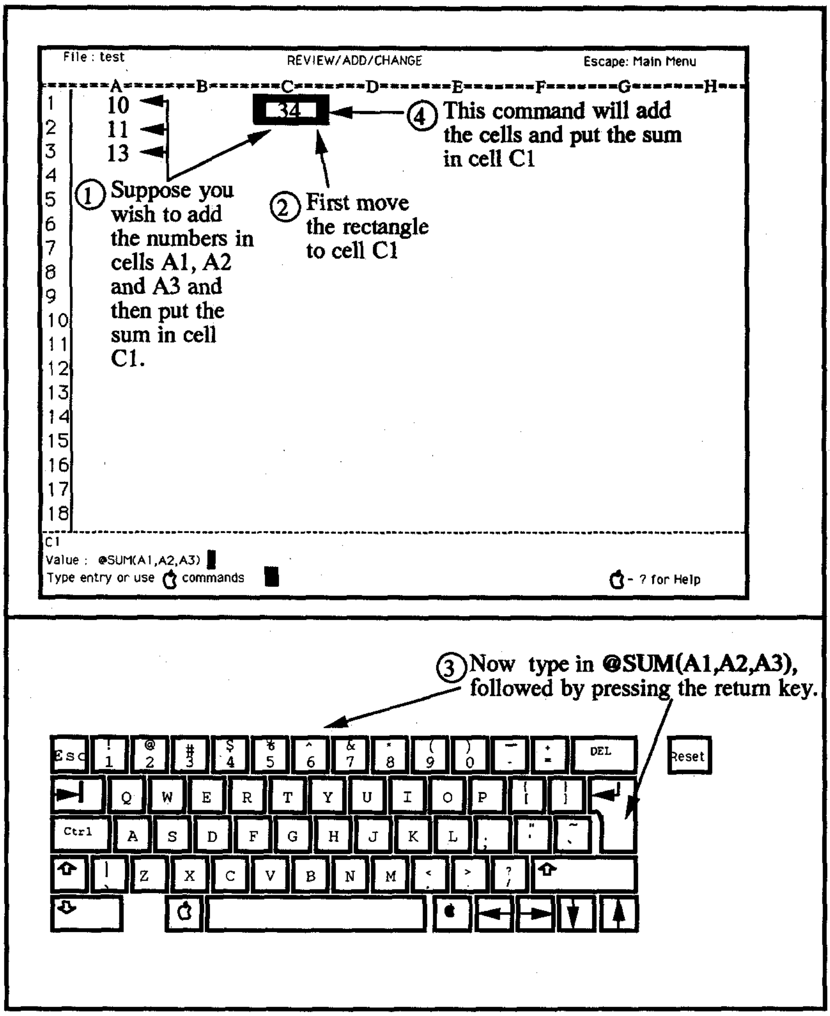
In summary, a split-attention effect exists if there is a significant difference between a conventional-manual-plus-computer group and a modified-manual-only group, because the conventional group subjects must split their attention between the manual and the computer. On the other hand, if there is a significant difference between a modified-manual-only group and a modified-manual-plus-computer group, a redundancy effect exists, because the computer is redundant when studying a self-contained modified manual. In accordance with our previous theorizing, it is predicted that the split-attention and redundancy effects would be displayed on high element interactive tasks such as performing functions but would disappear on low element interactive tasks such as moving through a spreadsheet.

Method

Subjects. Thirty Year 7 students from a Sydney high school participated in the study. All 30 students had previous experience with computers during primary school. The instructions used in the experiment were designed as an introduction to a spreadsheet package. For this reason, only students with no previous exposure to spreadsheet programs were used.

Materials. As with Experiment 2, the instructional materials consisted of two sets of manual instructions (conventional and modified) for the three groups of the experiment. The conventional instructions consisted of textual instructions designed to be used with a commonly used spreadsheet package. The instructions were not simply taken from the manual, because some parts used technical language unsuitable for Year 7 students. For that reason, the instructions were adjusted to make them more readable for the students. The modified instructions contained virtually identical textual information to the conventional instructions. This textual information was physically integrated with diagrams of the computer screen and keyboard. As with Experiment 1, the modified manual was designed to be self-contained. An example of the modified-manual instructions is displayed in Figure 2.

Computer Screen



Computer Keyboard

FIGURE 2 An example of the modified-manual instructions used in Experiment 2.

The test materials consisted of equipment for both written and practical tests. The written test was in the form of a test booklet containing four test problems. The first two problems involved moving the cursor around the screen (Problem 1) and inserting or deleting data (Problem 2). They were based entirely on the low element interactivity information of sections C and D of Appendix B. The first problem was divided into eight parts. The first four parts required students to provide the keys that would move the spreadsheet's rectangular cursor to a particular location. For example, "Indicate what key(s) are required to move the rectangle to the far left of the screen." The next four parts were reverse problems in which students were asked to indicate what would happen if certain keys were pressed. One mark was allocated for each correct part, giving a total mark out of 8. For the second problem, the students were given a spreadsheet entry and were asked what key(s) would delete a numeral from the entry and then confirm the entry. Two marks were allocated for this problem, one mark for correctly deleting and one mark for correctly confirming.

Problems 3 and 4 were function code problems and incorporated the high element interactivity material of sections A and B of Appendix B. For both these problems, students were provided with a diagram of the spreadsheet with various numbers entered into cells of the spreadsheet. For Problem 3, the subjects were given a function code and asked to work out what number would be calculated if the code were entered into the spreadsheet (see section A of Appendix B). Students were asked to provide all work. The function code given was @sum(C2, A1, A2). This code requires students to locate three numbers at coordinates C2, A1, and A2 of the spreadsheet and to add them. Four marks were allocated for this problem: one mark each for locating each of the three numbers and one mark for correctly adding the numbers. Each of these marks is associated with high element interactivity information. To locate a number, students must relate the appropriate part of the function code (e.g., A1) with the appropriate location on both the row and column components of the spreadsheet and read the number. Once the three numbers are read in this way, the nature of the interaction between them must be ascertained from the function code. In this case, they must be summed. Each of these activities requires students to relate several elements as indicated in section A of Appendix B.

For Problem 4, students were asked to provide the function code that would add three particular numbers from the diagram of the spreadsheet. To answer this problem, students had to locate the coordinates for each number and incorporate them into a function that would add the numbers. Assuming that most students would answer this problem in an all-or-none fashion, scoring was either right or wrong, with partial scores not allocated. Again, incorporating three numbers into a function via a coordinate system involves a high degree of interactivity between the various elements, as indicated in section B of Appendix B.

The practical test consisted of three parts and was conducted with the spreadsheet software package loaded on the computer. For the first part, the experimenter asked the student to perform a series of eight moves to various locations on the spreadsheet. For example, the students were asked to "Move the cursor to the top of the spreadsheet." One mark was given for each correct move, giving a total practical test score out of 8 for this part. The information needed for this part was low in element interactivity (see section C of Appendix B). For the second part of the test, students were asked to type in a number, delete a digit in the number, and then confirm the entry. Three marks were allocated for this part, one mark each for correct typing, deleting, and confirming. Again, element interactivity was low for this part (section D of Appendix B). For the third part of the test, students were shown a spreadsheet file on the computer screen with numbers entered into various cells. The experimenter selected three numbers from the computer screen. The student was asked to type in the function that would add the three numbers. The software did not permit invalid function entries. If the student entered an invalid function, the experimenter recorded this and asked the students to write their intended answer on a provided sheet of paper. This task was similar to Problem 4 of the written test and involved high element interactivity (section B of Appendix B). It also was judged as either correct or incorrect.

Procedure. The procedure was similar to Experiment 1. The experiment was conducted in two phases, and students were tested individually. Students in both the conventional-manual-plus-computer group and the modified-manual-plus-computer group worked through their instructions on the computer. The software was loaded on the computer, and the computer screen was identical to the diagram of the computer screen in Figure 2. As with Experiment 1, the students were familiarized with the layout of the keyboard and the computer screen and were asked if they had any problems. The experimenter monitored the students during the instructional phase to ensure that they were continually interacting with the computer. If a student failed to press a key in a 30 sec period, the experimenter intervened and answered any queries. Students in the modified-manual-only group had no contact with the computer and were simply asked to study the instructions. All three groups were asked to indicate when they had finished with the instructional material. Time to completion was noted.

During the test phase, the instructional materials were not available to the students. Students first attempted the written test. There was no time limit on the test, although a problem could not be reattempted after it had been answered. The practical test followed. Students were asked to perform each of the activities described in the Materials section. An experimenter marked each move as either correct or incorrect.

Results and Discussion

The variables under analysis were instruction time and written test and practical test scores. Written test and practical test times were not analyzed for this experiment. Some students failed to answer many written and practical problems, resulting in very rapid test times that in no way reflected actual performance. Means and standard deviations are provided in Table 4. An analysis of variance (ANOVA) indicated a significant effect of time to study the instructional materials, $F(2, 27) = 13.4$, $MS_e = 6{,}960.78$. Duncan range tests indicated that the modified-manual-only group required significantly less time to study the materials than either of the other two groups, which did not differ significantly from each other. These results are not particularly surprising. The students in the modified-manual-only group were not required to interact with the computer, whereas the other two groups continually interacted with the computer during the instructional period. Of more importance to this experiment was whether differing instructional treatments had consequences on written and practical test performance.

As mentioned in the Materials section, the written test consisted of four problems. Problems 1 and 2 were low element interactive problems, because they tested for knowledge of deleting, confirming, and moving around the spreadsheet. Problems 3 and 4 were high element interactive problems, because they tested knowledge of function codes. Inspection of the means reveals very little difference among the three groups on Problems 1 and 2. There was no significant difference among the groups on either Problem 1, $F(2, 27) = .15$, $MS_e = 1.51$, or Problem 2, $F(2, 27) = .13$, $MS_e = .26$. This result is consistent with the findings of Experiment 1, which also found no significant differences among the three groups on low element interactive tasks. The lack of a difference on Problem 2 was likely to be due to asymptotic effects, because the conventional-manual-plus-computer, modified-manual-plus-computer, and modified-manual-only groups had 6, 6, and 7 subjects, respectively, out of the 10 per group who made no errors on this problem. Asymptotic effects were less likely to have influenced the results of Problem 1, because the number of subjects who made no errors for this problem were 2, 3, and 1.

TABLE 4
Instruction Times, Written Test Scores, and Practical Task Scores for Experiment 2

		Written Test Problem Scores			*Practical Task Scores*	
Group	*Instruction Time (sec)*	*1*	*2*	*3*	*1*	*2*
Conventional-manual-plus-computer						
M	438.5	6.4	1.6	0.5	7.5	2.4
SD	113.8	1.3	0.5	1.3	0.5	0.7
Modified-manual-plus-computer						
M	441.8	6.3	1.6	1.5	7.3	2.1
SD	59.1	1.5	0.5	1.8	0.7	0.9
Modified-manual-only						
M	272.9	6.6	1.7	3.6	7.5	2.6
SD	66.6	0.8	0.5	1.3	0.5	0.5

A significant difference between groups was obtained on Problem 3, which consisted of high element interactivity sections, $F(2, 27) = 11.78$, $MS_e = 2.13$. Duncan range tests indicated that the modified-manual-only group was significantly different from the other two groups, which did not differ from each other. The difference between the modified-manual-only group and the conventional-manual-plus-computer group indicates a split-attention effect. The difference between the modified-manual-only group and the modified-manual-plus-computer group indicates a redundancy effect.

Individual sections of Problem 3 can be analyzed in terms of the number of subjects who were correct. These data are presented in Table 5. Analyses using Fisher Exact Tests indicate that, with the exception of the third step, requiring a value for A2, significantly more modified-manual-only subjects were correct on each of the four steps than either the conventional-manual-plus-computer group or the modified-manual-plus-computer group. There was no significant difference between the modified-manual-only and modified-manual-plus-computer groups when calculating A2. Nevertheless, these results indicate remarkably strong split-attention and redundancy effects.

Similar differences were also found on Problem 4. Because this problem required the production of a single function, it was only scored correct or incorrect. Seven students from the modified-manual-only group solved this problem. This compared with three from the modified-manual-plus-computer group and only one from the conventional-manual-plus-computer group. A Fisher Exact Test between the modified-manual-only and the conventional-manual-plus-computer groups confirmed that there was a significant difference between these two groups with respect to number of students solving the fourth problem, indicating the split-attention effect. A Fisher Exact Test between the modified-manual-only group and the modified-manual-plus-computer group also found a significant difference with respect to number of students solving this problem, indicating the redundancy effect.

Problems 1 and 2 of the practical test were low element interactive problems, because they tested for ability to type, confirm, delete, and move around the spreadsheet. Problem 3 was a high element interactive task, requiring the student

TABLE 5
Number of Subjects Successfully Completing the Individual Steps of Problem 3 of the Written Test for Experiment 2

		Step			
Group	*n*	*1*	*2*	*3*	*4*
Conventional-manual-plus-computer	10	2	1	1	1
Modified-manual-plus-computer	10	4	4	5	2
Modified-manual-only	10	9	9	9	9

Note. All steps involve high element interactivity.

to enter an appropriate function code. As with Problems 1 and 2 of the written test, there was little difference between the means on Problems 1 and 2 of the practical test. There was no significant difference between the groups for either Problem 1, $F(2, 27) = .4$, $MS_e = .34$, or Problem 2, $F(2, 27) = 1.25$, $MS_e = .51$. These results are similar to Problems 1 and 2 of the written test. Although there were no significant differences, as hypothesized, for low element interactivity material, it is difficult to draw any firm conclusions from these practical tests, because the results may be due to asymptotic effects. The number of conventional-manual-plus-computer, modified-manual-plus-computer, and modified-manual-only subjects who were correct on Problem 1 was 5, 4, and 5, respectively. For Problem 2, the equivalent data are 5, 4, and 6, respectively.

The third practical problem required students to write a function code and so involved high element interactivity. Eight students from the modified-manual-only group solved Problem 3, compared with 3 from the modified-manual-plus-computer group and none from the conventional-manual-plus-computer group. Separate Fisher Exact Tests confirmed that there was a significant difference between the modified-manual-only and the modified-manual-plus-computer groups, indicating the redundancy effect and a significant difference between the modified-manual-only and the conventional-manual-plus-computer groups, indicating the split-attention effect.

The results are in accordance with our predictions. On low element interactive tasks, there was no significant difference between the groups on either written or practical problems, although some of these results may have been due to asymptotic effects. The remarkable feature of this experiment was the clear differences favoring the modified-manual-only group on the high element interactive problems. The modified-manual-only group outperformed the other two groups on both written and practical function code problems, despite having had no previous exposure to the computer before testing. The modified-manual-only group showed such a degree of superiority that, on some problems, there was very little overlap between this group and the other two groups, which had considerable contact with the computer during the instructional phase. This result is similar to the findings of Experiment 1, which also found strong differences favoring a modified-manual-only group on tasks with a high level of element interactivity. Although the first experiment found differences between a modified-manual-only and a conventional-manual-plus-computer group, yielding a split-attention effect, this experiment also found differences between a modified-manual-only and a modified-manual-plus-computer group, yielding a redundancy effect.

We believe that the results of this experiment are most readily explained by cognitive load theory. If materials impose a naturally high cognitive load generated by high element interactivity, as was the case with the CAD/CAM materials of Experiment 1 and the function code tasks of this experiment, then the format of presentation is critical. A self-contained, modified manual designed to reduce extraneous cognitive load displayed its superiority over other presentation formats by eliminating split-attention and redundancy.

In contrast, materials with a low level of element interactivity impose a relatively light cognitive load. Under these circumstances, the extraneous cognitive load generated by differing presentation formats should not be as important. This lack of an effect when dealing with low element interactivity material was consistently demonstrated in Experiments 1 and 2. Nevertheless, although the results were consistent with the hypothesis, some of them could also be explained by asymptotic effects. For this reason, it is important to use low element interactivity materials with a sufficiently high information content to ensure that any lack of differences between groups cannot be attributed to asymptotic effects. Experiment 3 used such materials.

EXPERIMENT 3

Experiments 1 and 2 demonstrated that, when subjects are learning to use computer programs that have sections with limited elements to learn but a high degree of element interactivity, a modified instructional format designed to reduce extraneous cognitive load was superior to a conventional format. However, not all computer packages have sections with a high level of element interactivity. For example, consider most modern word-processing packages. A word-processing novice is faced with many individual elements to learn, such as typing in text; learning how to move a cursor around the screen; and deleting, inserting, and replacing text. Although there are many elements to learn, there is little interaction between elements. On most word-processing packages, one can begin typing as soon as the system has been booted. Initial typing of text can commence with nothing else being learned. Learning how to move the cursor on the screen and deleting, replacing, and inserting text can all be learned independently. This is in stark contrast to the CAD/CAM and spreadsheet packages that do not permit the learner even to begin using the package in its intended manner until high element interactivity material has been assimilated.

We have asserted that, when dealing with materials with little or no element interactivity, the intrinsic cognitive load generated is relatively low. Under these conditions, the extraneous cognitive load generated by the format of presentation may not be a critical factor. In other words, when learning to use a word-processing package, the presentation techniques that we are interested in may be of little importance for any of the material. Experiment 3 investigated this possibility with a commonly used word-processing package. The elements listed in Appendix C indicate the low level of element interactivity of the task.

We used the same experimental design as in Experiment 2, with three differing presentation formats. Unlike Experiments 1 and 2, differences between presentation formats were not expected on any section of the material, because the intrinsic cognitive load generated by the instructional materials may not have been sufficiently high to make the format of presentation critical to learning. Nevertheless, the total amount of information presented was expected to be sufficient to eliminate the asymptotic effects that influenced some of the low element interactivity data of Experiments 1 and 2.

Method

Subjects. The subjects were 30 Year 7 students from a Sydney high school. All students had previous experience with computers during primary school. Because the instructional package was designed as an introduction to a word-processing package, only students with no previous exposure to word-processing programs were used.

Materials. The instructional materials consisted of two sets of manual instructions (conventional and modified) for the three groups. Both sets of instructions were designed as an introduction to moving the cursor around the screen in a word-processing package. The conventional instructions consisted of textual instructions taken from the manual of a widely used word-processing package. As with Experiments 1 and 2, the revisions that were made to the instructions were only in the interest of clarifying minor ambiguities. The modified instructions contained textual information similar to the conventional instructions. This information was physically integrated with diagrams of the computer screen and keyboard. An example of the modified-manual instructions is displayed in Figure 3.

The test materials consisted of a two-page test booklet, as well as the apparatus for practical tests. The written test consisted of 10 problems. The first 5 problems asked students to draw the key or keys required to move the cursor to a specific location. For example, one problem asked students to "Indicate what key(s) are required to move the cursor to the bottom of the screen." The next 5 problems asked students to explain what would happen to the cursor if particular keys were pressed. These 5 problems were the reverse of the first 5 problems in that, rather than being asked which key(s) were required for a particular action, students were asked what would happen if a particular key or keys were pressed. Each problem was judged as either correct or incorrect. One mark was allocated for each problem, giving a total written test score out of 10.

The practical test was conducted with the word-processing package loaded on the computer. The experimenter asked the student to perform a series of 10 cursor moves on the computer screen. For example, the student was asked to "Move the cursor to the next tab stop." One mark was given for each correct move, giving a total practical test score out of 10.

Procedure. The general procedure was identical to Experiment 2.

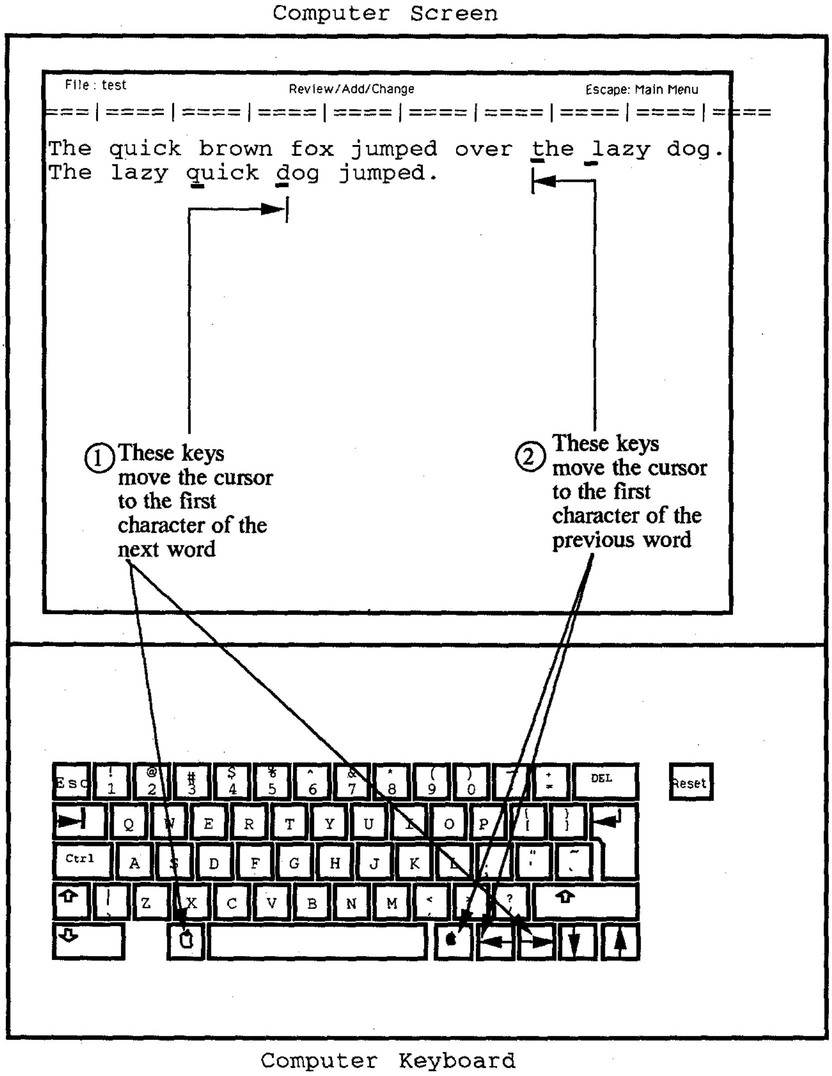


FIGURE 3 An example of the modified-manual instructions used in Experiment 3.

Results and Discussion

Instruction time and written test and practical test scores were the variables under analysis. Means and standard deviations are presented in Table 6. Written test and practical test times were not analyzed for this experiment, because students failed to answer many written and practical problems resulting in, for some students, very rapid test times unrelated to actual performance. This was similar

TABLE 6
Instruction Times, Written Test Scores, and Practical Task Scores for Experiment 3

Group	*Instruction Time (sec)*	*Written Test Scores*	*Practical Task Scores*
Conventional-manual-plus-computer			
M	140.7	6.0	6.9
SD	24.3	2.1	1.4
Modified-manual-plus-computer			
M	145.8	6.9	6.9
SD	19.6	1.7	1.7
Modified-manual-only			
M	117.4	6.0	7.3
SD	21.4	1.6	1.6

to Experiment 2 but in contrast to Experiment 1 where the subjects attempted all written and practical problems.

The instruction times were entered into an ANOVA, which indicated a significant effect, $F(2, 27) = 4.8$, $MS_e = 478.3$. Duncan range tests indicated that the modified-manual-only group spent significantly less time working through their instructions than the other two groups, but there was no significant difference between the conventional-manual-plus-computer and the modified-manual-plus-computer groups. These results were anticipated, considering that the modified-manual-only group simply had to study their instructions and were not required to interact with the computer. The other two groups, which did not differ in their instruction time, were both required to interact with the computer while working through their instructions.

Inspection of the means in Table 6 reveals very little difference between the three groups on the test scores. The groups did not differ significantly on either the written test, $F(2, 27) = .86$, $MS_e = 3.14$, or the practical test, $F(2, 27) = .22$, $MS_e = 2.44$. On the written test, one person in the conventional-manual-plus-computer group obtained full marks, whereas, on the practical test, one person in each of the conventional-manual-plus-computer and the modified-manual-plus-computer groups obtained full marks. All other learners made errors, indicating that the total amount of information exceeded learners' ability to assimilate it. The lack of significant differences is not likely to be due to asymptotic effects.

The results of this experiment are clearly different from the results of Experiments 1 and 2. In Experiments 1 and 2, the format of presentation was shown to be a critical factor on some sections of the material, with a modified-manual-only group clearly outperforming alternative presentation modes that permitted learners to use the computer while learning. That pattern of results was not repeated in this experiment. Both the conventional-manual-plus-computer and the modified-manual-plus-computer groups performed at the same level as the modified-manual-only group. We believe the explanation most consistent with the data relates to the nature of the instructional material. Because most elements of the word-processing package could be learned in isolation, there was little element interactivity and, therefore, a relatively light cognitive load when compared with the CAD/CAM package. Under these circumstances, any extraneous cognitive load imposed by the presence of the computer was not an important factor.

EXPERIMENT 4

The previous three experiments, using computer-based material, suggested that element interactivity may be a determining factor in the demonstration of the split-attention and redundancy effects. Results indicated that a self-contained, modified manual was superior to other presentation formats when the learning material involved a high level of element interactivity. No such advantage was demonstrated for low element interactive tasks. We believe that this finding is of considerable significance and has serious implications for computer-based training. However, cognitive load theory, used to generate the experiments, is quite general and in no way is intended to be restricted to computer-based instruction, which is but one example of training with technical equipment. Very often, technical instruction in educational and industrial settings involves considerable exposure to technical, noncomputing apparatus such as scientific and engineering equipment. As with computer-based instruction, conventional methods of introducing learners to technical equipment are fairly stereotyped. The learner usually begins by working through a manual or set of instructions that refer to specific features of the equipment necessitating, or at least inviting, interaction with the equipment. Once again, we have a split-attention situation. To use the equipment, learners must split their attention between information in the manual and technical equipment entities.

A self-contained manual format that aims to reduce the need to attend to the apparatus may have benefits with noncomputing equipment similar to those benefits found using computing equipment. Experiment 4 was designed to test this hypothesis. Specifically, the experiment investigated whether the advantages of a self-contained modified manual extended beyond computing instructions to training with noncomputing technical equipment.

As shown in Experiments 1, 2, and 3, the benefits of a self-contained manual were demonstrated only if the instructional material imposed a high level of element interactivity. Experiment 4 used electrical engineering materials that involved a relatively high level of element interactivity. The specific area of investigation was the testing of electrical appliances. When an electrical appliance is manufactured, a number of tests are performed to ensure that the appliance is safe and operating properly. The experiment used instructional notes on four tests of an electrical kettle with a megger meter (a device used to measure resistance). The four tests were (a) the earth continuity conductor, (b) the insulation resistance between the element and the frame, (c) the insulation of the flexible lead (or more generally, insulation of the earth from the active and neutral), and (d) the continuity of the electrical circuit. The instructions for each of the four tests entailed a high degree of element interactivity. For instance, to understand the test for earth continuity (see Figure 4), the learner must simultaneously consider the relations among the setting of the megger meter, where the earth lead of the megger meter is placed on the appliance, where the other lead of the megger meter is placed on the appliance, and the reading that results from the test. There is also a high degree of element interaction between the four individual tests. For example, the two insulation tests relate to each other in terms of the settings used, subtests required, placement of leads, and readings required. Appendix D provides an estimate of the interacting elements required to carry out the four tests. Each section of the Appendix indicates the interacting elements for a particular test.

The three groups of Experiments 2 and 3 were retained for Experiment 4. In accordance with cognitive load theory and the results of Experiments 1 and 2, we predicted that a self-contained modified-manual-only group would exhibit

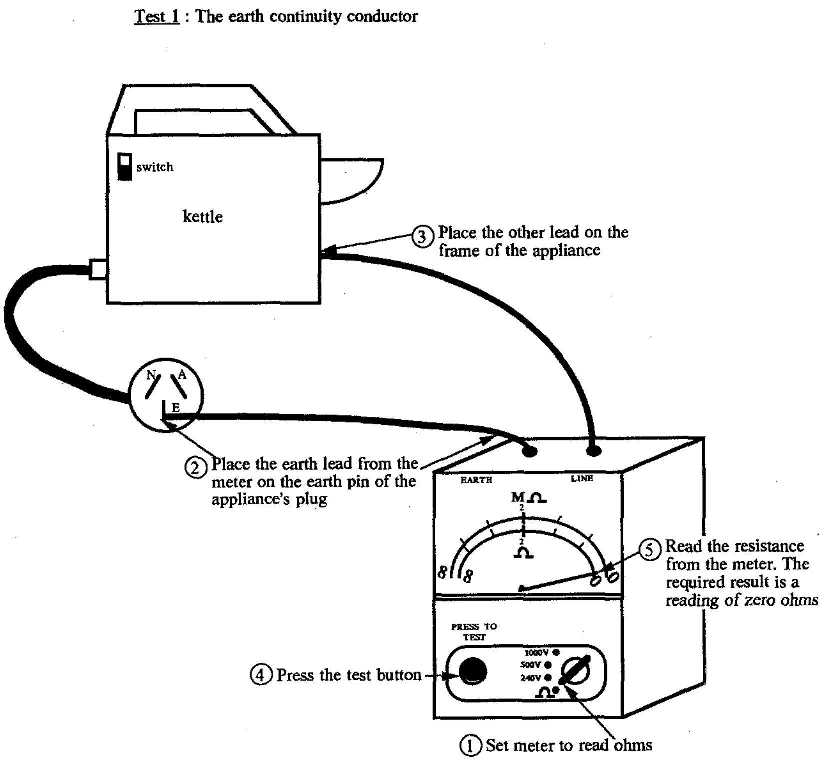


FIGURE 4 An example of the modified-manual instructions used in Experiment 4.

superior performance over a conventional-manual-plus-electrical-apparatus group and a modified-manual-plus-electrical-apparatus group. In other words, the split-attention and redundancy effects demonstrated with computer-based materials were expected using the electrical materials just discussed.

Method

Subjects. The subjects were 30 first-year trade apprentices from a Sydney company. All subjects had completed at least Year 10 of high school and were enrolled in first-year trade courses at various technical colleges. All 30 subjects had some previous exposure to a megger meter and were familiar with its use. No subject, however, had previous experience testing an electrical appliance.

Materials. As with Experiments 2 and 3, there were two sets of manual instructions (conventional and modified) for the three groups of the experiment. The conventional instructions consisted of the textual instructional steps required to perform each of the four discussed tests. The conventional notes were designed for use with a battery-powered megger meter and a 240 volt electrical kettle. The modified instructions contained identical textual information to the conventional instructions. This textual information was physically integrated with diagrams of the megger meter and electrical kettle. An example of the self-contained modified-manual instructions is displayed in Figure 4.

The test materials consisted of equipment for written and practical tests. The written test consisted of four problems. The first problem was divided into four parts. Each part contained a diagram of an electrical kettle and a megger meter with no visible leads. Above each diagram was the name of a specific test (e.g., insulation of the flexible lead). The subjects were required to indicate on the diagrams where the leads should be placed for each of the four tests. One mark was allocated for the correct placement of leads for a single test, giving a total mark out of 4 for the four tests. None of the parts of this problem could be answered adequately without knowing the relations among all of the components of the electrical system, so the knowledge required to answer each part was high in element interactivity.

The second problem consisted of 10 parts that posed specific problems about relations between individual tests, for example: Which test(s) require a lead to be placed on the frame of the appliance? or Which test(s) require a reading of 0 ohms? A correct response was allocated a mark, giving a total out of 10 for Problem 2. This problem was essentially a multiple-choice test with 10 parts or problems. Each part had to be answered by indicating one or more of the four tests taught. The parts varied in the extent to which subjects had to consider the entire circuit when answering the problem. For example, when answering a problem such as "Which test(s) require a lead to be placed on the frame of the appliance?" without guessing, subjects can either consider the entire circuit, which would involve high element interactivity, or they can simply memorize the appropriate answer, which would involve low element interactivity. Memorizing the appropriate answer is likely to lead to more mistakes, because it is arbitrary. In contrast, a problem such as "Which test(s) require a reading of 0 ohms?" probably can be more readily answered by simply memorizing the appropriate answer rather than considering all of the electrical components. In fact, most but not all of the problems could be answered readily in isolation from the other components of the circuit. The test format and content permitted but did not encourage the use of high element interactivity knowledge.

Problems 3 and 4 were transfer problems with high element interactivity. They were designed to investigate if the knowledge gained from testing the electrical appliance could be applied to other electrical systems. Specifically, Problem 3 tested if the knowledge of insulation resistance acquired from the electrical kettle instructional materials could be applied to an alternative electrical system, namely, a main switchboard with conductors in permanent wiring (i.e., a domestic electrical wiring system installed in most homes). Students were presented with a diagram of a main switchboard with conductors in permanent wiring and a diagram of a megger meter. One lead of the megger meter was drawn at the appropriate testing place on the diagram. Subjects were asked to use this hint to perform the appropriate insulation test on the electrical system. This problem could be judged as either correct or incorrect. A correct response involved using the hint to indicate the appropriate setting for the megger meter, indicating on the diagram where the other lead should be placed, and indicating what reading would be expected.

Problem 4 tested if knowledge of earth continuity could be applied to a typical domestic wiring system, namely, a main switchboard with conductor sheaths leading to domestic light switches, wall sockets, and lamp holders. Students were presented with a diagram of this electrical system as well as a drawing of a megger meter. As with Problem 3, one lead was drawn on the diagram as a hint to subjects. Subjects were asked to test the system for earth continuity. This test involved steps identical to those required for Problem 3 and was judged either correct or incorrect.

There were two practical tests. The first test required the use of the megger meter and the electrical kettle. Subjects were asked to perform each of the four previously described tests of the electrical kettle. A test was judged to be successful if a subject correctly completed all of the steps involved. With four tests required, a mark out of 4 was given for this practical test. Because each of the steps involved in a single test required knowledge of the relations among the components of the electrical system, element interactivity was high. The second practical test was a transfer task. Subjects were given a fluorescent light with electrical wires installed. The subjects were also given a megger meter and asked to perform any safety tests they felt were necessary. The two required tests were earth continuity and insulation resistance. Subjects were allocated one mark for successfully completing the steps involved in a test. Thus, two marks were allocated for the second practical task. Once again, because the steps of each test required knowledge of the relations among the individual components of the system, element interactivity was high.

Procedure. The procedure was very similar to that of the previous experiments. Subjects in the conventional-manual-plus-apparatus group and the modified-manual-plus-apparatus group worked through the notes while actually performing each of the four tests using the megger meter and the electrical kettle. If the subject failed to perform a step in a 30 sec period, the experimenter intervened and answered any queries. As with the previous experiments, the close monitoring of subjects insured that all subjects in these two groups successfully completed the instructional materials. Subjects in the modified-manual-only group had no contact with the electrical apparatus. They simply studied the self-contained manual, and, thus, for this group, there was no check on whether a task had been completed.

Instructional materials were not available to subjects during testing. Subjects were first asked to attempt the written test. As with the previous experiments, no time limit was placed on the test, and no problem could be reattempted after it was answered. The practical tests followed. The first practical task required subjects to perform the four tests of the electrical kettle. The experimenter judged each test as either correct or incorrect. The second practical test required two safety tests to be performed on a fluorescent light. Once again, the experimenter judged each test as either correct or incorrect.

Results and Discussion

The variables under analysis were instruction time, written test time, and written and practical test performance. Means and standard deviations are displayed in Table 7. An ANOVA indicated a significant difference in time to process the instructions, $F(2, 27) = 13.27$, $MS_e = 3{,}366.05$. Duncan range tests indicated that the modified-manual-only group spent significantly less time processing their instructions than the other two groups, but there was no significant difference in instruction time between the conventional-manual-plus-apparatus and the modified-manual-plus-apparatus groups. These results are similar to Experiments 2 and 3 and were expected, given that the conventional-manual-plus-apparatus and the modified-manual-plus-apparatus groups had to interact with the electrical equipment. Of interest were the results from the written and practical tests.

An ANOVA indicated a significant difference among groups in time to complete the written test, $F(2, 27) = 5.14$, $MS_e = 13{,}720.42$. Duncan range tests indicated that the modified-manual-only group required less time to complete the written test than the other two groups generating split-attention and redundancy effects, but there

TABLE 7
Instruction Times, Written Test Scores, and Practical Task Scores for Experiment 4

Group	Instruction Time (sec)	Written Test Time (sec)	Scores: Written Test 1	Written Test 2	Practical Test 1	Practical Test 2
Conventional-manual-plus-apparatus						
M	364.6	632.9	0.6	2.0	0.8	0.4
SD	66.1	139.5	0.7	1.1	0.4	0.5
Modified-manual-plus-apparatus						
M	356.7	634.7	1.0	2.2	1.3	0.4
SD	52.3	122.6	1.1	0.9	0.7	0.7
Modified-manual-only						
M	245.1	488.4	3.0	5.1	3.3	1.7
SD	54.6	81.6	0.9	2.6	0.8	0.5

was no significant difference between the conventional-manual-plus-apparatus and the modified-manual-plus-apparatus group.

With respect to written test scores, an ANOVA indicated a significant effect on Problem 1, $F(2, 27) = 19.93$, $MS_e = .83$. Duncan range tests indicated that the modified-manual-only group scored significantly higher than the other two groups, which did not differ significantly. The numbers of subjects correct on each part of Problem 1 are indicated in Table 8. Fisher Exact Tests indicated that the modified-manual-only group had significantly more subjects correct on each of the four parts than either of the other two groups. Strong split-attention and redundancy effects were obtained on this problem, which required knowledge of the relations among the components of the electrical system and so was high in element interactivity.

TABLE 8
Number of Subjects Successfully Completing the Individual Steps of Problems 1 and 2 of the Written Test for Experiment 4

Group	*n*	Problem 1 Step 1	2	3	4	Problem 2 Step 1	2	3	4	5	6	7	8	9	10
Conventional-manual-plus-apparatus	10	0	0	3	3	1	1	0	1	8	3	1	2	0	3
Modified-manual-plus-apparatus	10	2	2	2	4	2	0	0	0	10	2	1	2	1	4
Modified-manual-only	10	7	6	9	8	3	4	2	7	10	3	5	6	4	7

Note. For each step of Problem 1, element interactivity was high. For each step of Problem 2, element interactivity was low.

On Problem 2, an ANOVA indicated a significant effect, $F(2, 27) = 10.35$, $MS_e = 2.91$. Duncan range tests indicated that the modified-manual-only group was significantly different from each of the other two groups, which did not differ significantly. The number correct on each of the 10 parts of Problem 2 is given in Table 8. With the exception of the fifth section of this problem, most subjects were incorrect on each of the other sections. Fisher Exact Tests yielded significant differences between the modified-manual-only group and the other two groups on the fourth and eighth parts of the problem and between the modified-manual-only group and the conventional-manual-plus-apparatus group on the 10th problem. The remaining 15 Fisher Exact Tests were not significant, but, as can be seen from the data in Table 8, the modified-manual-only group was superior on almost all parts, and this superiority generated the significant ANOVA showing the split-attention and redundancy effects. We suggest that the more limited range of differences among the groups on this problem compared with Problem 1 was due to an increased tendency for subjects to attempt to answer the multiple-choice problems by relying on isolated memories for individual facts and procedures rather than on relations among components of the system. The test problems and format permitted the use of high element interactivity knowledge but encouraged the use of low element interactivity knowledge.

Six subjects from the modified-manual-only group successfully completed Problem 3, which was a transfer problem. This compared with one from the modified-manual-plus-apparatus group and none from the conventional-manual-plus-apparatus group. Separate Fisher Exact Tests confirmed that there was a significant difference between the modified-manual-only group and the conventional-manual-plus-apparatus group with respect to number of subjects solving this problem, thus indicating a split-attention effect. A redundancy effect was also indicated with a significant difference between the modified-manual-only group and the modified-manual-plus-apparatus group. Similar results were found for Problem 4, another transfer problem. Seven subjects from the modified-manual-only group successfully completed this problem. This compared with one from the modified-manual-plus-apparatus group and one from the conventional-manual-plus-apparatus group. Once again separate Fisher Exact Tests confirmed split-attention and redundancy effects. The transfer tests of both Problems 3 and 4 tapped high element interactivity knowledge. Transfer cannot be carried out successfully without the knowledge of one electrical system being transferred to another system, in its entirety, with all of its interacting elements.

Practical test results also favored the modified-manual-only group. Results from the first practical task yielded a significant ANOVA, $F(2, 27) = 40.04$, $MS_e = .44$. Duncan range tests indicated that the modified-manual-only group successfully performed significantly more tests of the electrical kettle than the other two groups, which did not differ. This result was obtained despite the modified-manual-only group having no contact with the equipment during the instructional phase. Indeed, the size of the difference between the conventional-manual-plus-apparatus group and the modified-manual-only group was remarkable. There was no overlap between these two groups, with 72% of the variance accounted for by the independent variable. The modified-manual-only group, despite not having carried out the tests previously, was able to do so easily and accurately. In contrast, the conventional-manual-plus-apparatus group, despite having successfully carried out the tests previously, gave little indication of knowing what they were doing.

Table 9 indicates the number of subjects correct on each of the four sections of the practical task. Fisher Exact Tests yielded a significant difference between the modified-manual-only group and both of the other groups on each section of the practical test, with the exception of the comparison between the modified-manual-only and modified-manual-plus-apparatus group on the first part of this practical task. The results on the first practical test have yielded very large split-attention and redundancy effects.

With respect to the transfer practical task, an ANOVA indicated a significant effect, $F(2, 27) = 17.09$. Duncan range tests indicated that the modified-manual-only group correctly performed significantly more tests on the transfer practical task than the other two groups, which did not differ significantly. Table 9 indicates the number of subjects correct on each of the two parts of this task. Significantly more modified-manual-only subjects successfully completed each section than either of the other two groups, according to a Fisher Exact Test, providing further evidence for the strength of the split-attention and redundancy effects in this experiment. Each of the practical tests could be completed only with knowledge of the entire electrical system, and thus the knowledge was high in element interactivity.

Results from both the written problems and practical tasks of this experiment strongly favored modified-manual instructions. Subjects from the modified-manual-only group required far less time to study their instructions and complete the written test and demonstrated their superiority in all areas of testing, including performance on the two transfer problems. On some tests, the differences among the groups were massive. For example, on Problem 1 of the written test, the modified-manual-only group recorded a mean score five times greater than the

TABLE 9
Number of Subjects Successfully Completing the Individual Steps of Both Practical Tasks of Experiment 4

		Practical Task 1 *Step*				*Practical Task 2* *Step*	
Group	*n*	*1*	*2*	*3*	*4*	*1*	*2*
Conventional-manual-plus-apparatus	10	5	1	2	0	4	0
Modified-manual-plus-apparatus	10	7	1	3	2	4	1
Modified-manual-only	10	10	7	9	6	10	7

Note. For all steps in Practical Tasks 1 and 2, element interactivity was high.

conventional-manual-plus-apparatus group and three times greater than that of the modified-manual-plus-apparatus group. It was only on Problem 2 of the written test, which encouraged students to access low rather than high element interactivity knowledge, that differences between groups disappeared on some parts of the problem.

Perhaps the most remarkable differences were found with the practical test results. Despite having no contact with the electrical apparatus during the instructional period, the modified-manual-only group clearly outperformed the other two groups with respect to the number of tests successfully performed on the electrical kettle. Thus, the conventional-manual-plus-apparatus and the modified-manual-plus-apparatus groups who successfully performed all the electrical tests on the kettle during the instruction period were unable to repeat the tests at the same success level as a modified-manual-only group who did not have the benefit of previous contact with the apparatus. Furthermore, all of the modified-manual-only subjects were superior to all of the conventional-manual-plus-apparatus subjects. In addition, subjects who studied the modified manual demonstrated far better performance on a practical transfer task. Specifically, the modified-manual-only group were far more able to practically apply knowledge of safety tests attained from the electrical kettle to a novel electrical configuration, namely, a fluorescent light.

The results of this experiment are of considerable interest for a number of reasons. First, it once again demonstrates the superiority of a self-contained modified manual in areas that involve a high level of element interactivity. We believe that this result, along with the results of Experiments 1 and 2, can be best explained using cognitive load theory. If the instructional material, in this case electrical engineering notes, imposes a heavy cognitive load generated by a high level of interaction between individual elements, the format of presentation becomes important. A modified manual designed to reduce the extraneous cognitive load imposed by the usual presentation procedure displayed considerable advantages over other presentation techniques. This superiority was demonstrated through the split-attention and redundancy effects of the present experiment, when learners accessed high element interactivity material, but was reduced when the structure of the test encouraged students to access low element interactivity knowledge. The other, perhaps, more important finding of this experiment is that the advantages of a self-contained modified manual seem to apply to technical areas beyond the computer-based domains discussed in the previous experiments. Thus, there is a degree of generality of the split-attention and redundancy effects.

GENERAL DISCUSSION

The model of cognitive processing when dealing with complex intellectual activities that we have adopted is likely to be seen as uncontroversial by most cognitive scientists. We assume that humans have a limited working memory but a very effective long-term memory capable of holding an enormous amount of information stored as schemas that can vary in their degree of automaticity. Schema acquisition and automation are learning mechanisms specifically designed to circumvent an ineffective working memory by making use of a highly effective long-term memory.

This cognitive model, in conjunction with some basic principles concerning the structure of information, can lead to instructional designs very different from those used currently. Information can be difficult to assimilate either because, in total, it is extensive (an issue not addressed in detail in this article) or because it is structured in a manner that forces us to process several elements simultaneously resulting in a heavy cognitive load. We are forced to process elements simultaneously when they interact and cannot be considered in isolation. Elements may interact either because of the intrinsic structure of the information or because of the manner in which it is presented or both. The intrinsic structure of information is unalterable, but, if elements interact and impose an extraneous cognitive load solely because of instructional design, restructuring is called for. It is likely to be especially important that an extraneous cognitive load caused by instructional design be reduced when the intrinsic cognitive load is high. If intrinsic element interactivity is high, additional element interactivity and its attendant extraneous cognitive load caused by inappropriate instructional designs can be fatal to learning. Because of our limited processing capacity, it is essential that information with a high degree of element interactivity be structured in a manner that permits learning through schema acquisition and automation to occur with minimal extraneous activities.

Two sources of extraneous cognitive load, split-attention and redundancy, were considered in this article. It was suggested that both the split-attention and redundancy effects are caused by the increased element interactivity associated with particular instructional designs. In line with the hypotheses, it was suggested further that the deficient instructional designs are likely to be of concern only when dealing with material that has a high cognitive load due to intrinsic element interactivity. It follows that the split-attention and redundancy effects are more likely to be observed using materials that have a high intrinsic level of element interactivity.

These predictions were tested using students learning to use computer software and electrical installation testing. If learners must simultaneously assimilate and mentally integrate elements in a manual and on a computer screen or associated with physical apparatus, cognitive load is likely to be higher than if all of the material is physically integrated in a manual. Physically integrated elements can be treated as a single element, obviating the need for mental integration and reducing the number of interacting elements. Comparing a physically integrated manual with a conventional manual and screen or apparatus yielded huge split-attention effects but only when associated with intrinsically high element interactivity materials. For computer and electrical wiring learning, the effect was tested using low element interactivity information. Using such material, the effect was reduced or disappeared.

Similar results were obtained in testing for the redundancy effect. If learners are given the integrated manual, the computer or apparatus is redundant. If the hardware is present, learners are likely to attempt to establish relations between the text and the hardware. The hardware provides additional elements that interact with the text, thus increasing extraneous cognitive load. The pattern of results was similar to that obtained in testing for the split-attention effect. The presence of the hardware was redundant and interfered with learning, but only in dealing with material that had a high level of intrinsic element interactivity.

The experimental designs used in this article compared the consequences of learning to use equipment from a manual alone or from manuals plus the relevant equipment. We did not include the equipment-only groups that are feasible if computer-assisted instruction is used. For example, in the first three experiments, it would have been possible to present all instructional material on the computer screen rather than in the manual as frequently occurs in computer-based training (e.g., Van Merrienboer & De Croock, 1992). Based on cognitive load theory, there is no a priori reason for supposing that appropriately designed computer-based learning should be ineffective. Providing split attention and redundancy are equivalent to that of the modified-manual-only groups and there are no other sources of extraneous cognitive load, computer-assisted instruction should be effective.

Although the experiments of this article have yielded powerful and theoretically consistent results, there are at least two limitations to generalizability that require noting. First, the results are only likely to be obtainable by a careful match between subjects and materials. We have suggested that element interactivity is a critical determinant of cognitive load. What constitutes an element and which elements must interact when learning a task are entirely dependent on the schemas that have been acquired by learners. For example, if learners have a fully automated schema covering the particular coordinate system that must be used, the interaction between the elements of that system is irrelevant. The entire system acts as a single element. An expert in the use of the CAD/CAM system used in Experiment 1 will have concatenated the elements listed in section A of Appendix A into a single schema. This schema can be used as an element in other, more advanced contexts. It follows that levels of element interactivity are critically determined by expertise, which in turn is determined by the extent of schema acquisition. Our experiments were able to yield their results because we used subjects who did not have the higher-order schemas capable of integrating the various interacting elements, or lower-level schemas, of the task.

The second limit to generalizability concerns tasks that include significant spatial-motor components. For such tasks, extended and immediate practice using equipment is likely to be essential. For example, one would not learn to type or to drive a car solely by thinking about it. Spatial-motor coordination is the primary aspect of these tasks that needs to be learned and is probably learnable only by carrying out the physical activity. Although our results should not be generalized to such activities, we propose the converse is also true: Procedures appropriate to spatial-motor learning should not be generalized to tasks with a high intellectual component. Because physical activity is essential when learning spatial-motor tasks, it does not follow that it is required when acquiring intellectual skills.

The suggestion that learning to use equipment might be facilitated by the absence of the equipment is likely to be seen as improbable by some. In defense of the suggestion, we would like to emphasize the following points.

1. The findings were not serendipitous. We predicted on the basis of cognitive load theory and previous work on the split-attention and redundancy effects that the presence of equipment could interfere with learning. That the results were generated by and so are consistent with a coherent theory should increase their plausibility. In turn, successful predictions inevitably have the effect of strengthening a theory.

2. Some of the effects found were enormous with, in some cases, very little or no overlap between groups. Although effect size is a function of many irrelevant factors (e.g., successful randomization, asymptotic effects due to material being slightly too difficult or too easy for the subjects used, intersubject variation due to differing initial knowledge levels), the huge effects found in, for example, Experiment 4, suggest a powerful phenomenon. The very size of the effects found should increase confidence in the plausibility of our suggestions.

3. In recent times, there has been a considerable emphasis on learning by doing, on associating learning with a clear activity, frequently a physical activity. This movement may have exceeded prudent limits. Although activity associated with learning frequently is motivating and, as previously indicated, essential when aspects of the task to be learned have critical spatial-motor components, we may need to recognize that, when learning a task with a considerable intellectual component, quiet contemplation and purely mental consideration of the various aspects of the task may be preferable to physically detectable activity. When the major intellectual components of a task involve acquiring complex concepts (i.e., concepts with high element interactivity), interacting with equipment may simply interfere with essential cognitive activities. In this sense, our findings, improbable though they may be on the surface, take on intuitive plausibility.

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APPENDIX A
Estimated Elements for Instructional Material Used in Experiment 1

A. Movement Between Coordinates Using the CAD/CAM Package

1. Note current position on the horizontal axis
2. Note current position on the vertical axis
3. Note the intersection of the horizontal and vertical positions

4. Locate the horizontal position of the goal coordinate
5. Locate the vertical position of the goal coordinate
6. Locate the intersection of the goal horizontal and vertical positions
7. Calculate the difference between the goal position on the horizontal axis and the current position on the horizontal axis
8. Relate the distance calculated in Number 7 to the required key press(es)
9. Calculate the difference between the goal position on the vertical axis and the current position on the vertical axis
10. Relate the distance calculated in Number 9 to the required key press(es)

B. Unidimensional Movement With the CAD/CAM Package

1. Hold down the appropriate movement function key (e.g., control key)
2. Press the appropriate arrow key the required number of times
3. Repeat Steps 1 and 2 until goal distance is reached

C. Drawing Lines With the CAD/CAM Package

1. Press the appropriate drawing function key

APPENDIX B
Estimated Elements for Instructional Material Used in Experiment 2

A. Calculating a Number From a Function Code

1. Identify the function to be performed (e.g., sum)
2. Read the first cell
3. Locate the column position of this cell
4. Locate the row position of this cell
5. Establish the relation between column and row by locating the intersection
6. Identify the number occupying the cell position
7. Repeat Steps 2 through 6 for the remaining cells in the function code
8. Perform the function on the identified cells

B. Constructing a Function Code to Manipulate Numbers on a Spreadsheet

1. Record the appropriate function code
2. Read first number
3. Locate this number on the spreadsheet
4. Record the column position of this number

5. Record the row position of this number
6. Repeat Steps 2 through 5 for the remaining numbers

C. Movement Within the Spreadsheet Package

1. Hold down appropriate movement function key
2. Press appropriate arrow key

D. Deleting, Inserting, and Confirming With the Spreadsheet Package

1. Press the appropriate function key

APPENDIX C
Estimated Elements for Instructional Material Used in Experiment 3

Movement Within the Word-Processing Package

1. Hold down appropriate movement function key
2. Press appropriate arrow key

APPENDIX D
Estimated Elements for Instructional Material Used in Experiment 4

Performing Safety and Operational Tests With a Megger Meter on an Electrical System

1. Test for *earth continuity* to ensure that there is no impediment to the flow of current between metallic nonelectrical sections of the equipment and the earth by:
   a. Setting the meter to read very low resistances
   b. Placing the earth lead from the meter on the earth of the electrical system
   c. Placing the other lead on metallic nonelectrical points on the equipment
   d. Performing test and ensuring a reading of 0 ohms
2. If the electrical system has an electrical element, test *insulation resistance* to ensure a high level of resistance between the electrical element and metallic nonelectrical parts of the equipment by:
   a. Setting the meter to read very high resistances

b. Placing one lead on a metallic nonelectrical point on the equipment
c. Placing the other lead on the active of the electrical system and recording result
d. Removing the lead on the active and placing it on the neutral of the electrical system and recording result
e. Both tests require a very large reading of at least 1 mega-ohm

3. Test *earth insulation* to ensure that the insulation of the electrical system has a high level of resistance between the earth and active and a high level of resistance between the earth and the neutral by:
   a. Setting the meter to read very high resistances
   b. Placing the earth lead from the meter on the earth of the electrical system
   c. Placing the other lead on the active of the electrical system and recording result
   d. Removing the lead on the active and placing it on the neutral of the electrical system and recording result
   e. Both tests require a very large reading of at least 1 mega-ohm
4. Test to ensure the *continuity* of the electrical circuit by:
   a. Setting meter to read low resistances
   b. If the electrical system has switch(es), making sure it/they are on
   c. Placing one lead from the meter on the neutral of the electrical system
   d. Placing the other lead on the active of the electrical system
   e. Performing test and recording result