

Understanding Instructions

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The understanding of instructions was explored within the context of cognitive load theory. Instructional material may be difficult to understand if it consists of many elements that must be held in working memory simultaneously. If the number of elements that must be processed exceeds working-memory capacity, then some elements must be combined into schemas before the material can be understood. A diagram may reduce cognitive load by providing such a schema. In a series of experiments, 3 different electrical resistor problems were given to students to complete, with instructions presented using diagrams or text. Results suggested that understanding depends on the degree of interaction among elements of information. However, if interacting elements can be incorporated into a diagrammatic schema, cognitive load will be reduced and understanding enhanced.

The ease with which we understand instructions and procedures is likely to be influenced by two general factors: the intrinsic complexity of the information and the manner in which the information is presented. These two factors interact both with each other and with relevant characteristics of the human cognitive system. As an example, material may be intrinsically complex but, because of the way humans process information, much easier to understand in one presentation format than in another. For other types of material, presentation format may not be particularly important. In this article, we consider the nature of these interactions, generate hypotheses on the basis of our theorizing, and test the hypotheses in a series of experiments. We begin by outlining those aspects of the cognitive system that we consider critical to understanding information.

Some Relevant Cognitive Processes

All conscious processing of information occurs in working memory, which is very limited in both duration and capacity (Miller, 1956; Simon, 1974). If students are required to follow instructions or engage in procedures that exceed working-memory capacity, then understanding, learning, and problem solving may be hampered (Sweller, 1988, 1989, 1993, 1994). For example, Sweller (1988) suggested that means–ends analysis, a problem-solving strategy commonly used by novices (Chi, Glaser, & Rees, 1982; Larkin, McDermott, Simon, & Simon, 1980), may

place an excessive burden on working memory, leaving insufficient resources for learning. When learning is the aim, alternatives to solving large numbers of problems by means–ends analysis may be desirable. Such alternatives need to be designed with the limited processing capacity of working memory in mind (see Sweller, 1989). Indeed, when designing instructional material, the limited capacity of working memory may be sufficiently critical to suggest that it is the most important factor that needs to be considered.

Although working memory is very limited, long-term memory has no known limits. The size of long-term memory became fully apparent only after work by researchers in an area for which long-term memory previously was not thought to be a significant factor: problem solving. De Groot (1946/1965) and Chase and Simon (1973) demonstrated that the primary factor distinguishing expert from novice chess players was not an ability to search for good moves but an enormous store of board configurations taken from real games. Chess masters recognize most of the configurations encountered in a game and know the best moves associated with each configuration. Simon and Gilmarin (1973) estimated that the number of configurations held in long-term memory could be as high as 100,000. Similar results to those of De Groot and Chase and Simon have been obtained in a wide variety of areas (see Egan & Schwartz, 1979; Jeffries, Turner, Polson, & Atwood, 1981; Sweller & Cooper, 1985). The real limits of long-term memory are unknown, but its size suggests that it is a critical component of intellectual functioning.

The form in which information is stored in long-term memory, or the manner in which we learn, will be considered next. Schema theory (e.g., Chi et al., 1982) provides the governing framework. A *schema* is defined as a cognitive construct that permits one to treat multiple elements of information as a single element categorized according to the manner in which it will be used. We have schemas for objects such as trees, which allow us to recognize a tree immediately despite the enormous amount of information impinging on our senses and despite the fact that each tree differs from every other tree. We have schemas that allow

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us to recognize an infinite variety of printing and handwriting styles. Chess masters have schemas that allow them to recognize a huge range of board configurations. Expert problem solvers have schemas that allow them to classify problems according to the manner in which they will be solved (Chi et al., 1982; Larkin et al., 1980). In summary, according to schema theory, the information stored in long-term memory is stored in schematic form and, at least in part, learning involves schema acquisition.

Learning also involves *automation*. Information can be processed either consciously or automatically (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). When we first learn to read letters, we must consciously consider the shape of each letter. With automation, the information contained in each letter is processed automatically. Nevertheless, we still may need to consider the letters of each word until reading words becomes automatic. Kotovsky, Hayes, and Simon (1985) showed that effective problem solving requires at least some degree of automation of the problem-solving operators.

Schemas can be automated. Learning to read involves the automation of schemas for letters and then words. Automated problem-solving schemas allow us to recognize a problem as belonging to a particular category instantly. If the relevant schema is not automated, we may need to consider the information carefully before realizing that the problem belongs to a particular category.

Although the learning mechanisms of schema acquisition and automation have the function of storing automated schemas in long-term memory, they may have another function: allowing us to ameliorate the effects of, or even bypass, limited working memory. By concatenating multiple elements into a single element, a schema reduces working-memory load. Similarly, automation allows us to process information with minimal demands on working memory. A major function of learning may be to reduce demands on working memory, in addition to the obvious function of storing information in long-term memory.

Impediments to Understanding: Three Sources of Cognitive Load

This cognitive model can be used to determine some of the factors important in understanding information. We are particularly concerned with understanding instructions; in this context, *understanding* is defined as the ability to follow instructions successfully and readily. There are three basic factors that can affect cognitive load when dealing with instructions. These factors are prior experience, the intrinsic nature of the material, and the organization of instruction.

Prior Experience

To understand information, we must be able to process that information in working memory. Whether we are able to do so depends on whether the amount of information exceeds the capacity of our working memory, and that, in

turn, is affected by the extent to which the information can be incorporated into automated schemas. If many elements can be incorporated into a single automated schema, then the working memory load will be minimal and the material will be easy to understand. Alternatively, if no schema is available and all the elements must be processed individually in working memory, understanding may fail. Thus, the presence or absence of appropriate schemas provides the first source of cognitive load. Cognitive load is reduced and understanding facilitated by the presence of appropriate schemas.

Nature of the Material

The presence or absence of schemas is more important for some types of materials than others because the intrinsic nature of various types of information can provide another source of cognitive load with consequences for understanding (Sweller, 1993, 1994; Sweller & Chandler, 1994). The elements of some material can be processed individually, without reference to other elements. Such material is easy to understand (but may be difficult to learn if it contains large amounts of information). Other material, containing the same amount of or less information, may be much more difficult to understand because the elements must be processed simultaneously in working memory. Students may find some subject matter difficult to understand because it consists of interacting elements that are difficult or impossible to learn in isolation. If multiple elements must be considered simultaneously because of high element interactivity, cognitive load may be high and understanding difficult. Understanding may occur only after the various elements have been incorporated into a schema held in long-term memory.

We will provide examples from the materials used in the following experiments in which students were required to follow instructions on how to connect together electrical resistors. Some of the instructions involved single-series connections, some multiple-series connections, and some parallel connections, with instructions being in either textual or diagrammatic form (see Appendixes A and B). A comparison of the intrinsic cognitive load associated with single-series, multiple-series, and parallel connection problems will be made by analyzing the amount of information that needs to be processed simultaneously for each problem when presented in textual form. The analysis assumes a student who has no background in connecting electrical resistors and therefore no schemas specific to this domain. We begin by considering the single-series problem, which consists of connecting pairs of resistors together in series. To connect one end of a 2-ohm resistor to one end of a 3-ohm resistor, there are only two resistor ends that need to be considered, namely, any one end of the 2-ohm resistor and any one end of the 3-ohm resistor. There are also only two resistor ends that need to be considered for each of the three other single-series connections. Moreover, all existing connections can be ignored each time a new connection is made. Because there are only two elements of information

(i.e., two resistor ends) that need to be held in working memory at any stage of the single-series problem, the element interactivity associated with this problem is relatively low.

Next, we consider the multiple-series problem, which consists of connecting many resistors together in series. For the first connection, there are, as in the preceding problem, only two resistor ends that need to be considered, namely, connecting any one end of the 2-ohm resistor to any one end of the 4-ohm resistor. However, to make the second connection, namely, connecting the other end of the 4-ohm resistor to one end of a 5-ohm resistor, three resistor ends need to be considered. Any end of the 5-ohm resistor needs to be connected to one of the unconnected ends of the existing connection. These are the unconnected ends of both the 2- and the 4-ohm resistors. These three ends need to be held in working memory simultaneously to select the appropriate connection. When attempting the third and fourth connections, there are once again three resistor ends that need to be considered. These include the two unconnected ends of the existing connection and any end of the new resistor that is being added to this existing connection. All other resistor ends can be ignored, because they already have a connection. The existing chain of connections, in essence, can be treated as one element. Connections are made only to the free, or unconnected, ends of this element, no matter how many resistors it consists of. Thus, with the exception of the first connection, the number of elements of information that need to be considered simultaneously is slightly higher for the multiple-series problem than it is for the single-series problem. However, processing three interacting elements still should not result in a substantial burden on working memory.

Last, we look at the number of resistor ends that need to be considered at each stage of the parallel connection problem, which involves connecting three resistors together in parallel. The first connection involves connecting an 8-ohm resistor to a 3-ohm resistor encompassing the same two elements as for both the series problems. The second connection, which is connecting the unconnected end of the 8-ohm resistor to the unconnected end of the 3-ohm resistor, requires all four ends of the two resistors in the existing connection to be held in working memory. When connecting in parallel, multiple connections can be made to any resistor end; therefore, all resistor ends of any existing construction must be considered irrespective of whether they already have been used. The third connection, namely, connecting one end of the 3-ohm resistor to one end of a 5-ohm resistor, requires that five resistor ends be considered. Because a connection can be made to both connected and unconnected resistor ends, all four resistor ends in the existing construction need to be considered along with either end of the 5-ohm resistor. For the fourth connection, which involves connecting the 3-ohm resistor to the end of the 5-ohm resistor that is not already connected to the 3-ohm resistor, all six resistor ends in the existing construction need to be considered.

On this analysis, element interactivity is substantially higher for the parallel problem than for either of the two

series problems. Choosing among six possible connections is likely to be substantially more demanding than searching among the two or three possibilities that is required for the series problems. It can be hypothesized that when presented in textual form, instructions for connecting pairs of resistors or for a series connection will be relatively easy to understand compared with those for a connection in parallel. The interacting elements of the more complex parallel connection should impose a heavier cognitive load that will interfere with understanding.

Organization

As an alternative to the preceding analysis, if the same parallel instructions are presented in diagrammatic form, the diagrams can be processed by previously acquired schemas that permit the entire set of connections to be processed as either a single element or a very limited number of elements. If, for example, the entire diagram can be held in working memory as a single, schematic entity, the cognitive load will be well within working-memory capacity irrespective of whether it depicts a series or a parallel connection. However, it might be noted that simply inserting the words *series* or *parallel* into the text format should result in that format resembling the diagram format, but only for people who already know what a series or parallel connection means. Such people already have a specific schema for the two types of connections. In the experiments described below, we used students who did not have such domain-specific schemas yet.

Because participants are assumed not to have specific schemas associated with the tasks, we might ask what other, more general schemas might be relevant. The series connections consist of links of physically serial elements that are common in everyday life. We are all familiar with (i.e., have automated schemas for) trains consisting of linked carriages or a series of connected building blocks. A diagram of the series connections may allow this schema to be used to understand the diagrammatic instructions. Similarly, a diagram of the parallel connections is likely to trigger a familiar schema even if parallel connections of electrical resistors have not been seen previously. Any rectangular object or drawing includes two parallel lines connected at their ends by another two lines. The horizontal steps of a ladder are connected by the two vertical sides in the same way that a diagram of a parallel connection may consist of horizontal resistors connected by vertical connectors. Thus, the several elements of a parallel connection, when presented in diagrammatic form, may be treated as a single element in the form of a previously acquired schema concerned with the parallel lines of rectangles. This schema should require no more working-memory capacity than a diagrammatic schema for serial connections. Understanding serial or parallel connections should be approximately equally difficult when the task is presented in diagrammatic form, but parallel connections should be considerably more difficult than serial connections when it is presented in textual form.

There are, of course, other reasons that a diagram can reduce cognitive load. Levin and Mayer (1993) pointed out that diagrams are usually more concise than equivalent textual statements and that the essential information tends to be perceptually clear. Concise material that highlights important information should reduce unnecessary cognitive effort and assist understanding. In a similar vein, a diagram makes spatial relations explicit, whereas a textual format requires the student to construct a mental representation of these relations. Also, a text must be processed sequentially, a method that is ill-suited to a task in which multiple constraints must be considered simultaneously. These factors result in diagrams reducing search (see Koedinger & Anderson, 1990; Larkin & Simon, 1987). For present purposes, the important point is that diagrams probably gain their effectiveness by reducing cognitive load. One of the reasons may be that diagrams can more easily trigger spatial schemas than text. Thus, instructional characteristics such as the use of diagrams provide another means of varying cognitive load. (There are many other ways of reducing cognitive load by instructional manipulation; see Sweller, 1993, for a review. Identical information can be presented in different ways with large differences in the burden on working memory and equally large differences in understanding.)

From this analysis, it can be seen that we are defining *understanding* in terms of working-memory load. Material may be difficult to understand because an appropriate schema is not available, the material consists of elements that cannot be learned in isolation because of high element interactivity, or instructional procedures are being used that impose a heavy cognitive load. All of these factors increase the number of elements that must be held simultaneously in working memory. In effect, understanding is reduced if any factor exists that requires people to process an excessive number of elements in working memory simultaneously.

Theoretical Summary

The theoretical assumptions may be summarized as follows. When we deal with higher intellectual processes, relevant aspects of our cognitive architecture include a limited-capacity working memory used to process current information and a very large long-term memory used to store information. Learning consists of schema acquisition and automation, with automated schemas having the dual function of providing a vehicle for storing information in long-term memory and reducing working-memory load. Whether or not new material is understood depends on the cognitive load imposed by the material. There are three relevant factors: (a) The characteristics of the learner: An excessive working-memory load is imposed if the information is not related to schemas held in long-term memory that can be used to incorporate and reduce in number the various elements of information. (b) The characteristics of the material: Schema acquisition is more important for some types of materials than other types. The intrinsic nature of some information is such that it is difficult or impossible to deal

with its elements serially. Because the elements interact, they must be dealt with simultaneously. If the elements have been incorporated into a schema held in long-term memory, the burden on working memory is slight and understanding is high despite high element interactivity. In contrast, if the elements must be considered discretely, high element interactivity will result in a high cognitive load and difficulty in understanding. (c) The characteristics of the instructional procedures: Some instructional procedures can result in students dealing with the material in a manner that unnecessarily increases the number of elements that need to be processed simultaneously in working memory, resulting in a heavy, extraneous cognitive load that interferes with understanding. The experiments of this article test some interactions among these factors.

Experiment 1

It was suggested previously that when a task involves an intrinsically high cognitive load (determined by element interactivity), it is important that the information be represented in a way that reduces extraneous cognitive load (determined by instructional design) to make it easier to understand. An intrinsically high cognitive load cannot be ameliorated, but total cognitive load can be reduced and understanding increased by the elimination of any extraneous cognitive activities or by inducing the student to use an appropriate schema. Instructional manipulations can reduce extraneous cognitive load, and this reduction may be critical when the material imposes an intrinsically high cognitive load.

In contrast, when a task does not involve an intrinsically high cognitive load, how the information is presented may be less important. With a low intrinsic cognitive load, the student may have sufficient cognitive resources to cope with an extraneous cognitive load if working-memory capacity is not exceeded. Assuming that diagrams can help to reduce the cognitive load associated with certain tasks, it is reasonable to expect that using a diagram to represent information will have beneficial effects when the intrinsic cognitive load associated with a task is high. However, these benefits may be reduced or even nonexistent when the intrinsic cognitive load associated with the task is low.

Experiment 1 was designed to test this expectation using the electrical resistor task described earlier. All students received the same three problems to complete. Half the students received the instructional material in a textual format and the other half in a diagrammatic format. The first problem involved connecting eight resistors together to give four pairs of connected resistors. The second problem required participants to connect together five resistors in series. The third problem involved connecting together three resistors in parallel. Each problem required a total of four connections. (See Appendix A for examples of the problems.)

It was hypothesized that for textually based information, the parallel connections would take longer to construct than the series connections but that this difference would be

reduced or disappear for the diagram-based information owing, at least in part, to the availability of schemas. Thus, we are hypothesizing an interaction. Instructional mode (textual or diagrammatic) should have a greater effect for high-element-interactivity materials than for low-element-interactivity materials.

Method

Participants. The participants were 30 Year 6 students (equivalent to U.S. sixth graders) from a Sydney primary school. They had no previous experience in the subject area of electricity or with connecting together electrical resistors.

Materials and procedure. Participants were tested individually. The experiment consisted of two phases. In the instruction phase, each student was shown which component was a resistor and which one was a connector. They were also shown physically how to join a resistor to a connector, after which each student was given as much time as necessary to read some background information on resistors and electricity. As part of this instructional phase, students were required to join a 5-ohm resistor to a connector to check that each student could physically make a connection and could distinguish one resistor from another. Any questions were answered during this phase.

In the test phase, participants were randomly divided into two groups of 15. All participants received the same three problems to complete. However, one group received all three problems in a diagrammatic format, and the other group received the problems in a textual format. The problems were all practical in nature. The first problem required the students to connect together four separate sets of two resistors in series; the second problem consisted of connecting together five resistors in series; and the third problem required students to connect together three resistors in parallel (see Appendix A). There were 10 resistors (ranging from 1 ohm to 9 ohms) placed in ascending order on the table in front of each participant. There were also six connectors. Participants had to choose the appropriate components from this selection.

The order in which the three problems were presented varied from participant to participant within each group, with a total of six

variations. This was done to neutralize any learning effects associated with order of presentation.

Time taken to complete each problem was recorded for each participant. Participants were given a maximum of 6 min to complete each problem. If the problem was not completed in the allocated time, the participant was shown how to make the correct connections, and the next problem was presented. If a participant reached an incorrect solution within the time limit, he or she was informed that an error had been made and was asked to retry the problem.

Results and Discussion

The top portion of Table 1 indicates mean number of seconds to solution for all three problems for both groups. All but one participant completed the problems within the time limit. This participant was in the parallel textual instruction group and was allocated the maximum time (360 s). To reduce inequalities in variance and skewness, a logarithmic function was applied to the data, the results of which also can be found in Table 1. All analyses reported below were carried out on the transformed data. A 2 (formats) \times 3 (problems) analysis of variance, with repeated measures on problem type, was performed. The results of this analysis indicated a significant difference in performance between the two instructional presentation formats, $F(1, 28) = 33.511$, $MSE = 0.037$ (the .05 level of significance is used throughout this article), with diagrams leading to faster solution times than text. There was also a significant difference in performance on the three test problems, $F(2, 56) = 13.697$, $MSE = 0.016$, with participants spending the least amount of time on the single-series problem and the greatest amount of time on the parallel connection problem. Last, and most important, there was a significant interaction between method of presentation and type of problem, $F(2, 56) = 8.540$.

Interaction contrasts were carried out to isolate the source

Table 1
Mean Number of Seconds to Solution for Experiments 1, 2, and 3

Presentation mode	Problem type					
	Single series		Multiple series		Parallel	
	<i>M</i>	LT	<i>M</i>	LT	<i>M</i>	LT
Experiment 1						
Diagram	59.93	1.764	63.13	1.775	65.60	1.800
Text	85.73	1.923	91.00	1.931	176.73	2.191
Experiment 2a						
Diagram	73.67	1.857	63.00	1.789	80.50	1.879
Text	147.42	2.137	214.00	2.191	410.00	2.499
Experiment 2b						
Diagram	112.67	1.993	110.58	1.935	73.50	1.847
Text	171.17	2.138	119.92	2.051	472.58	2.587
Experiment 3						
Diagram	71.17	1.845	68.42	1.818	69.08	1.816
Text	78.92	1.890	85.67	1.896	128.92	2.054

Note. LT = logarithmic transformations.

of the significant interaction. They revealed a significant Group \times Problem interaction using the multiple-series and parallel problems, $F(1, 56) = 12.943$, and the single-series and parallel problems, $F(1, 56) = 12.615$, but no significant interaction using the single- and multiple-series problems, $F(1, 56) < 1$. These results indicate that, relative to the diagram format, the textual format shows a greater increase in solution times between either of the series problems and the parallel problem.

While the students were being tested, it became apparent that some of them may have been unclear whether the parallel problem presented in the textual format consisted of a single problem made of up two components or two separate problems. Some students who may have found the instructions ambiguous either took the first connection apart before attempting the second connection or thought they had completed the problem after attempting only the first parallel connection. Five students incorrectly took the first connection apart before attempting the second part of the problem. Six students indicated that they thought they had completed the problem after completing the first connection. Some of these students were told to carry on and finish the problem. These students fell into both categories, resulting in a total of 8 of the 15 students who may have been unclear whether the parallel problem was a single problem or two separate problems. No students attempting the parallel problem presented in a diagrammatic format provided any evidence of these misconceptions. Nevertheless, it is also possible that (consistent with present theorizing) students took the first connection apart before attempting the second part of the problem simply because of cognitive overload. These students may have had difficulty deciding what to do next and taken the existing connections apart to restart the problem. This issue is addressed further in subsequent experiments.

The significant interaction between method of presentation and type of problem is of primary interest. This result conforms closely with our theory-based expectations. As suggested by our estimates of element interactivity, the parallel problem is substantially more adversely affected by the change in format (from diagram to text) than is either of the two series problems.

Experiment 2a

In the previous experiment, time to completion was used as an indicator of the cognitive load associated with understanding different instructions when presented in either a textual or a diagrammatic format. Although time to follow instructions can be seen as a measure of how difficult the instructions are to understand, it would be valuable to provide an additional, more direct measure of the cognitive load.

Secondary tasks have been used by many researchers as a measure of spare mental capacity (Britton, Glynn, Meyer, & Penland, 1982; Kerr, 1973; Lansman & Hunt, 1982). According to Kerr (1973), secondary tasks can be used to measure the degree to which a primary task uses limited

mental resources. If a pair of tasks are performed simultaneously, with the primary task's capacity needs given priority, secondary-task performance should provide a measure of the residual mental resources that are not being used by the primary task. Assumptions that are implied in the secondary-task paradigm include an information-processing system with a fixed or limited capacity and a mental workload composed of linearly additive components (Knowles, 1963; Senders, 1970). Performance on the secondary task accordingly can be seen to be a measure of the degree of difficulty or cognitive load associated with the primary task.

For Experiment 2a, a secondary task was used as an additional measure of the cognitive load associated with the primary tasks. It has been suggested by several researchers (e.g., Kerr, 1973; Knowles, 1963; Pew, 1979) that a secondary task should be easy to perform and learn, should provide as little interference as possible with the primary task, should allow for continuous scoring, and should not reduce the quality or quantity of primary-task performance. Moreover, it should be physically possible to perform the two tasks at once. Response to a tone provides one such secondary task. Accordingly, the secondary task in the present research involved using a foot pedal to respond to a tone. It was assumed that the time participants took to respond to the tone was an indicator of how cognitively demanding the primary task was: The more cognitively demanding the primary task, the longer the response time. More specifically, increases in the difficulty of understanding the instructions should result in increases in response latencies. Again, an interaction can be predicted. Larger differences in response times between the parallel and series tasks should be obtained for the textual than the diagrammatic group. Potentially, the secondary task could provide a clear indicator of the cognitive load associated with understanding the various instructions.

Method

Participants. The participants were 24 Year 5 students from a Sydney primary school. They had no previous experience in the subject area of electricity or with connecting together electrical resistors.

Materials and procedure. Participants were tested individually in a quiet room. The experiment consisted of both an instruction and a test phase, as in the previous experiment. The instruction phase was almost identical to that of the previous experiment. However, in addition to being shown what a resistor and connector are and being given some background information to read, participants were also given an explanation of the secondary task. They were told they had to press the foot pedal as quickly as possible whenever they heard the tone. A practice session followed, in which each participant was asked to respond to six tones as quickly as possible, using the foot pedal. If a participant was not able to use the foot pedal proficiently, this practice session was repeated. In particular, participants had to learn to release the foot pedal after each response. It was emphasized to participants that they would have to perform the two tasks simultaneously but that the more important task was to join the resistors together according to the instructions they would be given.

The test phase followed a similar procedure to Experiment 1

with respect to the primary task. However, a minor modification was made to the instructions for the textual version of the parallel problem. The word *and* was inserted at the beginning of the second part of this problem to clarify that the task consisted of a single problem with two related components and was not made up of two separate parts. All participants received the same three problems to complete, with half the participants receiving them in a diagrammatic format and the other half in a textual format, resulting in 12 participants per group. While performing the primary task of connecting resistors together in different ways, the students also had to respond to the tones generated by a computer, using the foot pedal. The tones were generated at random intervals in the range of 5–20 s.

A computer was used to record time to completion and response times for each problem. Participants were given a maximum of 15 min to complete each problem. As in the previous experiment, if a participant reached an incorrect solution within the time limit, the participant was informed that an error had been made and was asked to retry the problem. If the problem was not completed in the allocated time, the participant was shown the correct solution before progressing to the next problem.

Results and Discussion

The mean times to completion are indicated in the second portion of Table 1. Two participants did not complete the parallel problem presented in a textual format, and one participant did not complete the multiple-series problem presented in a textual format. They were allocated the maximum time of 900 s. A logarithmic function was applied to the primary task data with all analyses carried out on the transformed data. The logarithmic transformed completion times can be found in Table 1. A 2 (formats) \times 3 (problems) analysis of variance, with repeated measures on the second factor, indicated that solving the problems using diagrams led to a significantly better performance than solving the problems using text, $F(1, 22) = 36.115$, $MSE = 0.094$; there was a significant difference in performance among the three problems, $F(2, 44) = 10.925$, $MSE = 0.028$, with the single-series problem requiring the least and the parallel problem the greatest amount of time to complete; and there was a significant interaction between method of presentation and type of problem, $F(2, 44) = 6.359$.

Interaction contrasts indicated a significant Group \times Problem interaction using the multiple-series and parallel problems, $F(1, 44) = 5.092$, and single-series and parallel problems, $F(1, 44) = 12.386$, but no interaction using the two series problems, $F(1, 44) = 1.595$. The increase in difficulty of the parallel problem over the series problems is more marked under textual than diagrammatic conditions.

Although these results closely mirror those obtained in Experiment 1, it might be noted that the mean time students took to complete the problems was considerably higher than in the previous experiment. This result can be explained by the fact that the students in this group were a year younger than those in Experiment 1 and may have found the tasks more challenging. Also, it is very likely that having to attend to the secondary task while connecting the resistors together slowed down performance on the primary task. However, the important point is that, for the group given

textual instructions, the students attempting the parallel problem took about twice as long to finish when compared to students attempting either of the series problems. In contrast, the mean times to completion for all the problems attempted using diagrammatic instructions were much more similar.

The response times for the secondary task are presented in Table 2. (A logarithmic transformation was not applied to these data because the marked inequalities in variance and skewness found for time-to-solution data did not occur.) A 2 (formats) \times 3 (problems) analysis of variance, with repeated measures on the second factor, indicated that there was no significant difference between the two presentation formats in average secondary-task response times, $F(1, 22) = 1.537$, $MSE = 95,351.694$; there also were no significant response-time differences among problems, $F(2, 44) = 1.073$, $MSE = 10,075.316$; and the interaction between method of instructional presentation and type of problem was not statistically significant, $F(2, 44) = 2.580$, $p < .09$. However, complementary simple effects tests indicated a significant difference in response times for the textual problems, $F(2, 44) = 3.470$, $p < .05$, but no significant difference in response times for the diagrammatic problems, $F(2, 44) < 1$. Newman-Keuls post hoc analyses on the textual group indicate that the response times to the tone while attempting the parallel problem were significantly slower than while attempting either of the series problems. There was no significant difference in response times for the two categories of series problems.

Although they are not as strong, these interaction results may lend support to the primary-task findings. When the cognitive load associated with the primary task (as indicated by both the times to complete the primary task and the theoretical analyses) increases, the response times to the tone become slower. When the element interactivity associated with a task is high, working memory is highly loaded and secondary-task performance is adversely affected. Conversely, when element interactivity is low, one has the cognitive resources available to perform relatively well on the secondary task.

Analysis of the solution modes used by students to solve the textual parallel problem indicated that four students incorrectly took the first connection apart before attempting the second connection. Five students indicated that they thought they had completed the problem after completing the first connection. In total, 8 of the 12 students may have been unclear as to whether the parallel problem was one single problem or two separate problems. Inserting the word

Table 2
Mean Response Times (in Milliseconds) to a Random Tone for Experiment 2a

Presentation mode	Problem type		
	Single series	Multiple series	Parallel
Diagram	767.75	754.67	743.00
Text	802.83	827.17	906.08

and between the two components of the parallel problem did not lead to a decrease in these types of mistakes.

Although it is indicated in the diagram that one can put two connectors on the same end of one resistor, this information is not stated explicitly in the textual instructions. Students must infer this information from the instructions. Larkin and Simon (1987) pointed out that having to make inferences from textual instructions that are explicit in diagrams is a primary reason for an increased cognitive load associated with textual instructions. Evidence for this factor comes from the finding that 4 students in the text group asked if they could put two connectors on the same end of one resistor while attempting the parallel text problem.

Further evidence of the need to make inferences from the textual instructions comes from the finding that 4 students attempting the parallel text problem attempted to make a connection by joining two ends of a resistor together with the single end of one connector (instead of joining one end of the connector to one resistor and the other end of the connector to the other resistor). The diagram indicates explicitly that this is not how a connection should be made. Students in the text group had to infer this procedure from the initial instructions on how to connect resistors. With a heavy cognitive load, such inferences are not always possible.

Experiment 2b

In Experiment 2a, the secondary task of responding to a tone was used as a measure of the cognitive load associated with the various primary tasks. Understanding the instructions of the primary task and responding to the tone of the secondary task are, of course, quite different activities. They may be activities that do not impinge sufficiently on each other for the secondary task to be an effective measure of the cognitive load of the primary task.

Many current conceptions of working memory indicate that it may consist of multiple stores or channels (e.g., Baddeley, 1992; Schneider & Detweiler, 1987). If this is so, responding to a tone may bear only a marginal relation to understanding the instructions of the primary task. A secondary task that requires participants to deal with information that is more closely related to that of the primary task could provide a more sensitive indicator of the cognitive load associated with the primary task. Moreover, as indicated by O'Donnell and Eggemeier (1986), it could be advantageous to choose a secondary task that requires continuous processing in working memory so that it is sensitive to any primary-task processing changes. Although these ideas are not in accordance with previous secondary-task recommendations, there is not a consensus in the literature as to what constitutes an ideal secondary task.

For Experiment 2b, an alternative secondary task, more likely to impinge on those aspects of working memory relevant to the primary task, was used. Because the primary task involves resistors identified by their numerical values, a suitable task would be recalling two-digit numbers that are presented while the primary task is being performed. Such

a task should result in a greater resource overlap between the primary and secondary tasks than would a response to a tone. Moreover, this task requires continuous processing in working memory. The cognitive load associated with the primary task should therefore have a greater effect on the performance of the secondary task.

Method

Participants. The participants were 24 Year 6 students from a Sydney primary school who had no previous experience in the subject area of electricity or with connecting together electrical resistors.

Materials and procedure. Participants were tested individually in a quiet room. As in the previous experiments, there was both an instruction and a test phase. The instruction phase was almost the same as in Experiment 2a. However, instead of participants being given practice in how to respond to a tone, they were given practice related to the memory task. Whenever a student heard a number recited from a tape recorder, the student had to indicate what the previously heard number was (except, of course, for the first number). Each student was given 15 two-digit numbers to remember and repeat during this practice session. It was then emphasized that the more important task to concentrate on was joining the resistors. However, students were also instructed to do their best to recall the numbers while connecting the resistors.

The test phase followed the same procedure as in Experiments 1 and 2a. All participants received the same three problems to complete, with half the participants receiving them in a diagrammatic format and the other half in a textual format. There were 12 participants per group. While performing the primary task of connecting together resistors, the students also had to recall the previous two-digit number recited from a tape recorder. Participants were given a maximum of 12 min to complete each problem.

Results and Discussion

The results for time to completion are indicated in the third portion of Table 1. All participants in the diagram group completed all problems, and all participants in the text group completed the single- and multiple-series problems within this time. However, 4 participants did not complete the parallel problem presented in a textual format. They were allocated the maximum time of 720 s. (It should be noted that in Experiment 2b, qualitative data concerning students' solution modes were not available, because experimenter activities had to be devoted heavily to the secondary task.)

The results replicated the previous findings. A 2 (formats) \times 3 (problems) analysis of variance, with repeated measures on problem type, was performed on logarithmic transformed data, which indicated that solving the problems using diagrams led to significantly better performance than solving the problems using text, $F(1, 22) = 26.269$, $MSE = 0.076$; there was a significant difference in performance when comparing the three problems, $F(2, 44) = 5.957$, $MSE = 0.052$, with the single-series problem requiring the least amount of time and the parallel problem requiring the greatest amount of time. As in Experiment 1, there was a

significant interaction between method of presentation and type of problem, $F(2, 44) = 14.193$.

Interaction contrasts indicated significant effects using multiple-series and parallel problems, $F(1, 44) = 22.464$, and single-series and parallel problems, $F(1, 44) = 20.424$, but no effect using the two series problems, $F(1, 44) < 1$. The interaction exists, therefore, because of differences in the ease of understanding the instructions for the three types of textual problems rather than differences in understanding the three diagrammatic problems, for the most part. Even though there was a descriptively unusual pattern in the results for the diagram group (with the parallel task being completed in less time than the two series tasks), these differences were not statistically significant.

A 2 (formats) \times 3 (problems) analysis of variance with repeated measures on the second factor was performed for error rates on the secondary task. Means are presented in Table 3. Like the results for time to completion, these results indicated that solving the problems using diagrams led to significantly fewer errors being made than solving the problems using text, $F(1, 22) = 22.634$, $MSE = 582.146$. There was no significant difference in the number of errors made while attempting the three different problems, $F(2, 44) = 0.193$, $MSE = 124.116$. In addition, there was a significant interaction between method of instructional presentation and type of problem attempted, $F(2, 44) = 4.384$. Interaction contrasts again indicated significant interactions using the multiple-series and parallel problems, $F(1, 44) = 8.201$, and the single-series and parallel problems, $F(1, 44) = 4.353$, but no effect using the two series problems, $F(1, 44) < 1$.

The results for error rates on the secondary task were broadly in line with the findings of the primary task and with the findings of the previous experiments. The results for both time to complete the primary task and percentage errors made on the secondary task again followed the same basic pattern. These results suggest that both indicators measure the same construct, which, according to our theoretical perspective, is cognitive load. The increase in the cognitive load associated with understanding the parallel instructions compared to understanding the series instructions was relatively greater when the instructions were presented in textual form than when presented in diagrammatic form.

Experiment 3

Although the use of secondary tasks to provide an independent estimate of relative cognitive load in Experiments

Table 3
Mean Percentage Errors Made on Secondary Task for Experiment 2b

Presentation mode	Problem type		
	Single series	Multiple series	Parallel
Diagram	27.08	31.33	22.08
Text	51.33	50.58	59.75

2a and 2b yielded results in broad accord with our hypotheses, some of the results were equivocal in some respects. The ambiguity may be due to problems with using secondary tasks. For example, Baddeley (1992) suggested that working memory for auditory and visual stimuli may be distinct to some extent. If so, the cognitive load associated with a visual primary task may be only weakly correlated with performance on a secondary task with stimuli presented in the auditory mode. On the other hand, a visually presented secondary task might physically interfere with the primary task to the extent that its use is effectively prohibited. For this reason, the independent measure of cognitive load used in Experiment 3 required participants to respond to a subjective rating scale after the completion of each problem to indicate how difficult they perceived the problem to have been.

The rating scale used was based on one modified by Paas (1992) from Bratfisch, Borg, and Dornic's (1972) scale for measuring perceived task difficulty (see also Paas & Van Merriënboer, 1993, 1994). The rating-scale technique, adapted from the field of psychophysics, is based on the assumption that participants can introspect on their cognitive processes and report the amount of mental effort spent on a task. Indeed, it has been shown that participants have no difficulty assigning numerical values to the items' imposed mental load and invested mental effort (e.g., Gopher & Braune, 1984). Similarly, reviews of the literature by Moray (1982) and O'Donnell and Eggemeier (1986) indicated that subjective measures of task difficulty correlate highly with objective measures. Also, rating scales have the advantage over secondary tasks of not intruding on primary-task performance. Recommendations for their use include (a) administering the rating scale as soon after the task is completed as possible to minimize loss of mental-load information from working memory; (b) giving careful consideration to the wording used for the scale; and (c) being aware that tasks that are most suited to mental workload ratings do not require excessive degrees of physical activity, because mental and physical workload may be confused by participants.

In Experiment 3, participants responded on a 7-point scale designed to translate their perception of amount of mental effort expended into a numerical value. The participants were asked to rate the problem they had just finished. The response choices were *very easy* (1), *easy* (2), *fairly easy* (3), *neither easy nor difficult* (4), *fairly difficult* (5), *difficult* (6), and *very difficult* (7).

In the previous experiments, there may still have been some participant ambiguity as to whether the textual, parallel-connections problem consisted of one or two problems and whether multiple connectors could be attached to one end of a resistor. For this reason, additional modifications to the procedure, detailed below, were made.

Method

Participants. The participants were 24 Year 5 students from a Sydney primary school who had no previous experience in the

subject area of electricity or with connecting together electrical resistors.

Materials and procedure. Participants were tested individually in a quiet room. As in the previous experiments, there was both an instruction and a test phase. The instruction phase was similar to that of Experiment 2; however, participants were all explicitly told they could put two connectors on the same end of one resistor. This was done to ensure that both diagram and text groups received the same information. In addition, participants were given an explanation of the subjective rating scale. They were told that after finishing each problem they would be asked to fill out a questionnaire indicating how difficult they felt the problem was. The seven options were explained to them, ranging from 1, which indicated that the problem was very easy, to 7, which indicated it was very difficult. Any questions relating to the rating scale were answered.

The test phase followed a procedure similar to that of the previous experiments. All participants received the same three problems to complete, with half the participants receiving them in a diagrammatic format and the other half in a textual format. The textual versions of the problems were modified to ensure the elimination of ambiguity as well as to ensure consistency of representation across problems. Each problem consisted of four points, and each point described a single connection. Moreover, the word *and* was included between each point for every problem to make it clear that all four points belonged together as part of a single problem (see Appendix B). After finishing each problem, each student completed the subjective rating scale.

There were 12 participants per group. Participants were given a maximum of 6 min to complete each problem.

Results and Discussion

The results for time to completion are indicated in the bottom portion of Table 1. All participants in the diagram group completed all problems, and all participants in the text group completed both the single- and multiple-series problems within this time. However, one participant did not complete the textual parallel problem. This participant was allocated the maximum time of 360 s. A 2 (formats) \times 3 (problems) analysis of variance, with repeated measures on the second factor, was conducted on the logarithmic transformed data. The results of this analysis indicated that problems solved using diagrammatic instructions were completed significantly faster than problems solved using textual instructions, $F(1, 22) = 8.835$, $MSE = 0.029$. Although there were differences in the expected direction when comparing the performance on the three problems (with the single-series problem being completed the fastest and the parallel problem taking the longest to complete), these differences were significant only at the 0.10 level, $F(2, 44) = 2.636$, $MSE = 0.016$. There was a significant interaction between method of instructional presentation and type of problem, $F(2, 44) = 3.917$.

Interaction contrasts indicated significant interactions using the multiple-series and parallel problems, $F(1, 44) = 4.803$, and the single-series and parallel problems, $F(1, 44) = 6.989$, but no effect using the two series problems, $F(1, 44) < 1$. These results indicate that the interaction is significant because differences in the ease of understanding the series and parallel instructions are greater for the textual than the diagrammatic materials.

It is important to note that only one student attempting the textual version of the parallel problem may have been uncertain as to whether it was one or two problems. The possible ambiguity associated with the previous versions of the textual parallel instructions appears to have been eliminated.

A 2 (formats) \times 3 (problems) analysis of variance, with repeated measures on type of problem, was performed for the subjective ratings made by each participant for each problem. Means are presented in Table 4. There was no significant difference in the perceived problem difficulty related to format, $F(1, 22) = 2.402$, $MSE = 3.331$. There was a significant difference in the perceived difficulty of the three problems, $F(2, 44) = 8.480$, $MSE = 0.513$, with the parallel task being judged as the most difficult and the single-series task as the easiest. The interaction between method of instructional presentation and type of problem attempted was significant, $F(2, 44) = 5.933$.

Interaction contrasts indicated significant interactions using the multiple-series and parallel problems, $F(1, 44) = 4.06$, and the single-series and parallel problems, $F(1, 44) = 11.725$, but no effect using the two series problems, $F(1, 44) = 1.988$. These results therefore confirm previous findings.

Additional analyses were conducted combining task performance and mental workload measures to obtain information on the relative efficiency of each instructional condition (see Paas & Van Merriënboer, 1993, for a detailed description of this approach). The efficiency of a learner's behavior is considered to be a measure of the relation between invested mental effort and performance. A particular instructional condition may be said to lead to more efficient behavior either if performance is higher than expected on the basis of mental effort scores or if invested mental effort is lower than expected on the basis of performance measures. This approach involves transforming both performance measures (P) and mental effort rating scores (M) into standardized *z* scores, which can be displayed in a two-dimensional plot of M versus P. Relative condition efficiency (E) can then be deduced by comparing the position of a point, representing an instructional condition, to points that represent other conditions. Relative condition efficiency is thus defined as "the observed relation between mental effort and performance in a particular condition in relation to a hypothetical baseline condition in which each unit of invested mental effort equals one unit of performance" (Paas & Van Merriënboer, 1993, p. 739). The

Table 4
Subject Rating Scale Means for Experiment 3

Presentation mode	Problem type		
	Single series	Multiple series	Parallel
Diagram	1.833	1.667	1.917
Text	1.833	2.250	3.333

formula used to calculate relative condition efficiency E is:

$$E = \frac{|M-P|}{2^{1/2}}$$

The $2^{1/2}$ in the formula is not necessary for statistical inference purposes but helps to scale E appropriately for its interpretation; see Paas and Van Merriënboer (1993). Positive values of the measure indicate that performance exceeds the invested mental effort, whereas negative values indicate the reverse. The mean relative-condition efficiency data are depicted in Figure 1.

A 2 (formats) \times 3 (problems) analysis of variance, with repeated measures on the second factor, was performed on the efficiency scores. There was a significant difference in the efficiency scores owing to presentation format, with diagrams being more efficient than text, $F(1, 22) = 5.868$ $MSE = 2.542$; there was also a significant difference in the

efficiency scores across the three problems, with the efficiency scores for the series problems being significantly higher than for the parallel problem, $F(2, 44) = 7.052$, $MSE = 0.536$; and there was a significant interaction between presentation format and type of problem attempted, $F(2, 44) = 7.620$. Interaction contrasts indicated a significant interaction using the multiple-series and parallel problems, $F(1, 44) = 7.274$, and using the single-series and parallel problems, $F(1, 44) = 14.508$, but no effect using the two series problems, $F(1, 44) = 3.318$.

These results indicate that when presented diagrammatically, the series instructions and the parallel instructions are much more similar in their efficiency than when presented textually. In other words, the mental effort required to process the instructions diagrammatically is more commensurate with performance. The close proximity of the diagrammatic single-series problem, the diagrammatic multiple-series problem, and the diagrammatic problem of

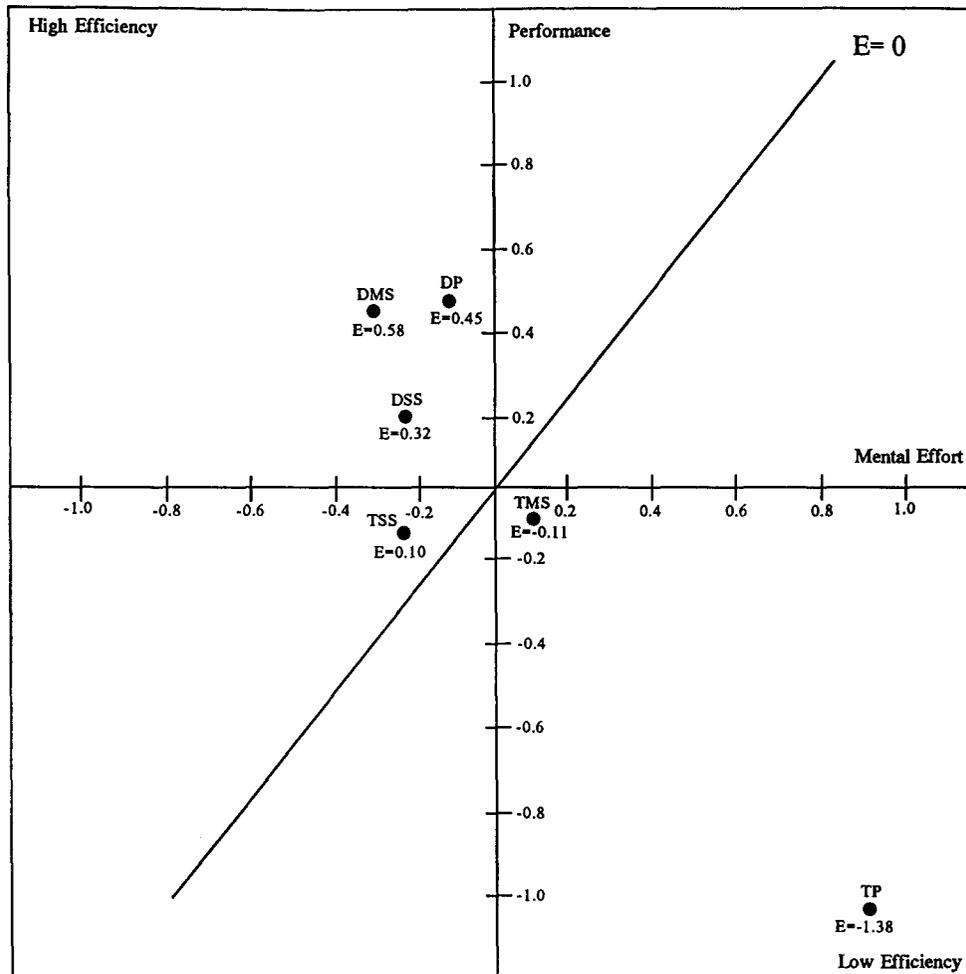


Figure 1. Relative condition efficiency (E) as a function of presentation format and problem type. DSS = diagrammatic single-series problem; DMS = diagrammatic multiple-series problem; DP = diagrammatic parallel problem; TSS = textual single-series problem; TMS = textual multiple-series problem; TP = textual parallel problem.

Figure 1 provides an indication of this point. In contrast, as also can be seen in Figure 1, when presented textually, the efficiency of the parallel instructions dropped precipitously compared to that of the series instructions. Despite the considerable mental effort required to process the parallel textual instructions, performance was poor.

General Discussion

We began this article by indicating that understanding could be interpreted in terms of cognitive load theory. It was suggested that information is difficult to understand if multiple elements cannot be processed individually because they interact. If the elements of the information interact, they cannot be understood in isolation but must be assimilated simultaneously, which can result in a heavy cognitive load. A heavy cognitive load can be avoided despite multiple, interacting elements if those elements are embedded in a schema. If they are incorporated in an automated schema, they act as a single element, cognitive load will be light, and understanding should be high. Whether information can be incorporated into a schema may depend on its mode of presentation. The same information can be presented in a manner that either does or does not encourage the use of previously acquired schemas.

These points were tested by increasing element interactivity under conditions in which the elements were unlikely to be incorporated in preexisting schemas and comparing the effects with presentation of the same information under conditions in which the elements were more likely to be incorporated into a schema. Students were presented with instructions for joining electrical resistors in series or in parallel. For textual instructions, for which preexisting schemas were not likely to be readily accessed, element interactivity was less in the case of resistors in series than in parallel, and accordingly, students took much longer to construct the parallel than the series connections. Furthermore, under textual presentation conditions, secondary tasks and subjective rating scores indicated that cognitive load was higher for construction of the parallel connections than for the series connections. In contrast, these differences did not occur when diagrammatic instructions were used.

These results closely mirrored our theoretical assessments of element interactivity for the three tasks. The theoretical assessments suggested that the textual parallel connection instructions should be harder to understand than the series connection instructions. In contrast, when the same instructions were presented in diagrammatic form, allowing them to be incorporated into schemas associated with diagrams, all instructions were equally easy to understand, and cognitive loads (as measured by time to completion, scores on secondary tasks, and subjective rating scores) were approximately equivalent. We can conclude, in accordance with our theorizing, that understanding instructions depends on the degree of element interactivity unless the elements can be incorporated into preexisting schemas that reduce cognitive load.

Our results can be related to the considerable body of

literature on picture versus text effects. Diagrams frequently assist learning (e.g., Mayer, 1989a, 1993; Mayer & Gallini, 1990). In support of our findings, Levin (1981) has argued that diagrams are most useful as an aid to understanding when materials are complex or difficult to understand. More specifically, Levin, Anglin, and Carney (1987), in a meta-analysis of 100 experiments, found that diagrams that organize events into a coherent structure, clarify complex and abstract concepts, or assist learners in recalling important information are most effective in enhancing learning. Also, diagrams may improve understanding because they make information more concise by summarizing or highlighting the essential information, or both (Levin & Mayer, 1993; Mayer, 1989b). Larkin and Simon (1987) and Koedinger and Anderson (1990) suggested that diagrams are effective because they reduce search and inference. More specifically, relations among elements are made explicit, and one can process all the essential information simultaneously (Winn, 1987). Organizing, clarifying, assisting recall, summarizing, highlighting, and reducing search and inference are likely to benefit understanding only under conditions in which working-memory load is high. From our perspective, a high memory load does not mean a large amount of information but a large amount of information that must be processed simultaneously because high element interactivity prevents it from being broken into simpler components. The advantage of diagrams over text should be lessened when information can be processed serially because element interactivity is low. This suggestion was confirmed in all experiments. When cognitive load was low because element interactivity was low, the advantage of diagrams was lessened compared to materials with a high cognitive load owing to high element interactivity.

The use of cognitive load theory to explain understanding can be applied to other findings. For example, in recent years there has been considerable interest and work in naive science concepts (e.g., McCloskey, Caramazza, & Green, 1980). Many students seem able to assimilate high school or even university science concepts but simultaneously hold naive, contradictory concepts that science courses are supposed to eliminate. They may have no difficulty solving problems requiring the use of two-dimensional kinematics, but when asked to indicate the rough trajectory of an object rolling off a cliff or falling from a plane, for example, they give answers suggesting no knowledge of the area.

In this situation, there has been a clear failure of understanding. Although the finding is likely to have multiple causes, cognitive load may be a contributory factor. In terms of cognitive load theory, students are able to consider the instructional material presented and also are able to consider real-life examples, but not simultaneously. The cognitive load imposed by considering both sets of materials and deriving the relevant relations between them may exceed working-memory capacity. It may be only after sufficient elements of the instructional material have been incorporated into schemas that enough capacity is available to integrate the instructional material with novel, realistic applications.

In conclusion, our experimental findings suggest that

difficulty in understanding is dependent not on the amount of information that must be assimilated but on the amount of information that must be held in working memory simultaneously. Consequently, to understand materials that are high in element interactivity and so impose a heavy working-memory burden, it is important to present the materials in a manner that minimizes extraneous cognitive load. For low-element-interactivity materials, mode of presentation should have less effect on understanding. Element interactivity and the manner in which information is presented interact with each other to influence understanding.

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Appendix A

Instructional Materials for Experiments 1 and 2

Instructions for Making Single-Series Connections

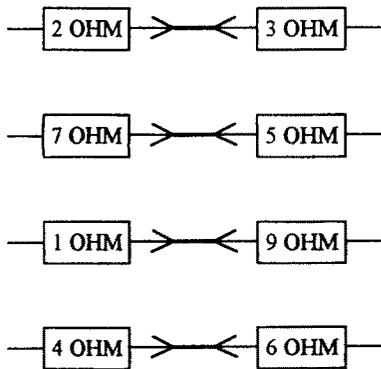
Textual Format

Using the resistors supplied, make the following connections:

- Connect one end of a 2 ohm resistor to one end of a 3 ohm resistor.
- Connect one end of a 7 ohm resistor to one end of a 5 ohm resistor.
- Connect one end of a 1 ohm resistor to one end of a 9 ohm resistor.
- Connect one end of a 4 ohm resistor to one end of a 6 ohm resistor.

Diagrammatic Format

Using the resistors supplied, make the following connections:



Instructions for Making Multiple-Series Connections

Textual Format

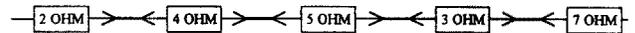
Using the resistors supplied, make the following connections:

- Connect one end of a 2 ohm resistor to one end of a 4 ohm resistor;
- and connect the other end of the 4 ohm resistor to one end of a 5 ohm resistor;

- and connect the other end of the 5 ohm resistor to one end of a 3 ohm resistor;
- and connect the other end of the 3 ohm resistor to one end of a 7 ohm resistor.

Diagrammatic Format

Using the resistors supplied, make the following connections:



Instructions for Making Parallel Connections

Note: For Experiment 2, the textual format was slightly modified and the word *and* was inserted at the beginning of the second half of the parallel problem.

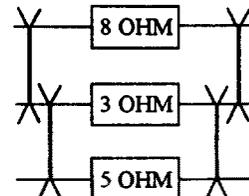
Textual Format

Using the resistors supplied, make the following connections:

- Connect one end of an 8 ohm resistor to one end of a 3 ohm resistor, and connect the other end of the 8 ohm resistor to the other end of the 3 ohm resistor;
- connect one end of the 3 ohm resistor to one end of a 5 ohm resistor, and connect the other end of the 3 ohm resistor to the other end of the 5 ohm resistor.

Diagrammatic Format

Using the resistors supplied, make the following connections:



Appendix B

Textual Instructional Materials for Experiment 3

Note: See Appendix A for the diagrammatic instructional materials for Experiment 3.

Instructions for Single-Series Connections

Using the resistors supplied, make the following connections:

- Connect one end of a 2 ohm resistor to one end of a 3 ohm resistor;
and
- connect one end of a 7 ohm resistor to one end of a 5 ohm resistor;
and
- connect one end of a 1 ohm resistor to one end of a 9 ohm resistor;
and
- connect one end of a 4 ohm resistor to one end of a 6 ohm resistor.

Instructions for Multiple-Series Connections

Using the resistors supplied, make the following connections:

- Connect one end of a 2 ohm resistor to one end of a 4 ohm resistor;
and
- connect the other end of the 4 ohm resistor to one end of a

5 ohm resistor;
and

- connect the other end of the 5 ohm resistor to one end of a 3 ohm resistor;
and
- connect the other end of the 3 ohm resistor to one end of a 7 ohm resistor.

Instructions for Parallel Connections

Using the resistors supplied, make the following connections:

- Connect one end of an 8 ohm resistor to one end of a 3 ohm resistor;
and
- connect the other end of the 8 ohm resistor to the other end of the 3 ohm resistor;
and
- connect one end of the 3 ohm resistor to one end of a 5 ohm resistor;
and
- connect the other end of the 3 ohm resistor to the other end of the 5 ohm resistor.

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Editorial Notice

Michael Pressley and Carole Beal, the Incoming Editor and Associate Editor, respectively, are now receiving submissions for the Journal. They expect no dramatic changes in the Journal and encourage educational scientists to consider submission of their most important empirical articles, theoretical statements, and integrative reviews on psychological processes pertaining to education. Pressley and Beal renew the Journal's commitment to efficient and timely feedback to submitting authors. As soon as it is apparent that a manuscript may eventually merit publication in the Journal, Pressley and Beal are dedicated especially to providing feedback that will permit efficient, effective revision, keeping rounds of revision to a minimum.