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It is safe to say that, in spite of increasing interest in non-verbal media, they are still less well understood than forms of communication that use verbal languages. By and large, non-verbal media express meaning through codes and conventions that rely upon spatial relationships among elements in the visual displays which encompass them, (which is why I have called them "spatial media" rather than the less precise though more usual "visual media").

Any consideration, however, of learning from spatial media, within the current cognitive paradigm, must be based upon an analysis and understanding of internal cognitive processes and forms of representation which enable learners to construct knowledge (Neisser, 1976; Piaget, 1967; Papert, 1980). This article therefore picks up some of the ideas expressed in earlier reviews of research related to cognitive processes and spatial media (Winn, 1980a, 1982a) and pursues them with a more particular focus on processing the spatial codes of these media.

A theme, derived ultimately from the debate about imaginal and propositional representation (Kosslyn, 1980, 1981; Pylyshyn, 1981), that will recur in this paper is the fundamental distinction in spatial processing between serial and parallel, or better, successive and simultaneous processes. Finally, the importance of such considerations for instructional design will be discussed.

Basic principles

Certain results from research into learning from spatial media (and into learning in general) have recurred with sufficient frequency that they are accepted as axiomatic. The following are some of these basic principles.

1. Spatial media and the information they contain involve a) elements, and b) relationships among them, each of which can be varied in instruction. A thorough discussion of this aspect of spatial media can be found in Knowlton's (1966) article "On the Definition of 'Picture,' ". The elements in any visual display, as Knowlton points out, can vary from the highly realistic to the completely conventional. One thinks of maps where buildings are shown as little pictures or as black dots. Similarly, the relationships among elements can vary in realism, from isomorphic to reality, as in topographical maps, to arbitrary, as in block diagrams.

2. In perception, all information is encountered sequentially, element by element. We tend to think of reading language as a sequential process and looking at spatial media as somehow holistic. However, we see by means of a series of rapid ocular fixations which take in only one detail of a visual display at a time, as studies of eye movements have shown (Yarbus, 1967). So while the order in which the elements in spatial materials are "read" may not be as predetermined as the order in which words are read in a text, they are nonetheless apprehended one after the other.

3. It is through the way in which these sequentially encountered elements in a visual display are synthesized into a meaningful aggregate that differences in processing occur. Das, Kirby and Jarman (1975, 1979) have proposed that there are two ways in which this synthesis can happen—simultaneously or successively. When perceived elements are synthesized simultaneously, all of the accumulated information is surveyable by the learner at any one time. Each new element in the visual display is added to the aggregate in memory in the same way that a piece is added to a jigsaw puzzle. In the case of successive synthesis, the order in which the elements are encountered is meaningful. There is not the necessity for the learner to be able to survey all of the accumulated information at once. People tend to conclude from this that text is synthesized successively and that visual displays are synthesized simultaneously. However, it is not as simple as that. Reading involves both processes, and as the meaning of a text becomes more complex, simultaneous synthesis becomes more important (Kirby and Das, 1977; Cummins and Das, 1977). This is because in more complex sentences meaning is accessible only if learners are able to survey information given early in the sentence at the same time as the information given later which modifies it. On the other hand, in processing spatial media, the succession of elements is often meaningful, as we shall see.

4. Learning occurs when the information presented in spatial media interacts with existing knowledge schemata, learner ability, learning strategy, learner perception of the task, and a whole host of other things. This interactive nature of learning has been discussed frequently (Salomon, 1979; Neisser, 1976; Bransford, 1979; Rumelhart and Norman, 1981) and will not be pursued here. But an implication of this particular principle is that there is no magic link between the forms that spatial media are given and the way that they are processed and learned. Too many other variables interact with media form and learning for prescriptive links (or "media utilization principles") to be established with any certainty.

Spatial codes and processing

We will now look at research into certain "spatial codes" and cognitive processing that is built upon these basic principles. Specifically, studies concerning the meaningfulness of elements in spatial media, relationships among elements and learning strategies will be discussed.

The elements in a visual display are either meaningful on their own or become meaningful only when combined

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with other elements. Cognitive processing is influenced by which of these two categories the elements of a particular visual display belong to, as two recent experiments have shown (Winn, 1982b). Subjects were shown either random sequences of letters or random sequences of lines on a computer screen. (When put together, the lines formed complete geometric figures.) Subjects had either to remember and draw the sequences of lines or letters in the order in which they were shown or draw the patterns (or figures) that the letters or lines formed when synthesized into an aggregate. These are obviously successive and simultaneous tasks. Subjects who saw the lines were far more successful with the simultaneous task than with the successive, while the reverse was true for subjects who saw letters. Since letters of the alphabet are more meaningful on their own (more "nameable" if you like) than isolated line segments from a figure, this suggests that meaningful elements are generally processed successively, while less meaningful elements are processed simultaneously. However, the contiguity of one element with the next is also a factor in this, as a second experiment showed.

Two more treatments were added in the second experiment. A third group of subjects was shown letters and had to recall just the position of each and mark it with an X. A fourth group was simply shown X's, the positions of which they had to recall. Only the simultaneous task was used. Subjects seeing letters but recalling only positions and subjects seeing X's performed significantly better than subjects having to recall letters and their positions. But these two groups still did not perform as well as subjects constructing figures out of lines, suggesting that the contiguity of elements (lines) in a geometric figure makes it easier to synthesize through simultaneous processing. When low-meaningful elements like X's are not contiguous, they can still be synthesized into patterns, though not so easily. And when the nature of each element has to be remembered as well as its position, performance is relatively poor. Interestingly, when subjects from the letters group were re-scored so that they were given a point whenever a letter was in the correct position, regardless of whether it was the right letter, their scores improved significantly and were no different from the two groups who drew X's.

What these two experiments suggest is that the meaningfulness of individual elements in spatial media affects the way in which they will be processed. In addition, the relative positions of the elements can be recalled best if they are contiguous and if only their position, not their name, has to be remembered. If meaning is deriveable from the elements themselves, it will be more difficult for learners to derive meaning from the patterns that the elements form.

An important influence on the way students process information in spatial media is the fact that we read English left to right, top to bottom. Learners tend to "read" spatial materials in the same way with the result that if the materials do not conform to the traditional format, difficulties arise. In a study of learning from diagrams (Winn, 1982c), students learned about the evolution of dinosaurs from a flow diagram. The animals evolved from left to right, and a time scale showing geological periods and time in millions of years ran across the top. A second diagram was prepared in which the dinosaurs were shown evolving from right to left with the time scale at the bottom. On tests of their knowledge of evolutionary sequence and classification by period and type of dinosaur, subjects who saw the reversed diagram performed significantly less well than those who saw the normal diagram. (On two tests, they performed no better than a control group.) Subsequently, eye movements of other subjects viewing the same materials have been recorded. While the analysis of these data has not been completed at the time of writing, initial analysis seems to suggest that the difficulty with the reversed diagram stems from its countering normal scanning behavior.

An aptitude-treatment interaction was found. For classification of dinosaurs by type, subjects who were low verbal and high spatial performed better on the reversed diagram than subjects who were high verbal and low spatial, there being no difference for the normal diagram. This suggests that learners who are better at processing spatial materials as patterns are less affected by departures from the normal way of presenting information in spatial media than those who would be more likely to process that information as sequences. While it is unlikely that spatial materials as perverse as the reversed diagram used in this study would be prepared by instructional designers, these findings certainly suggest precepts of which instructional designers would do well to take heed.

Spatial media can also be used to convey information about conceptual distances among concepts. (We think of a cat as being "closer to" a dog than to an aardvark.) In an earlier study (Winn, 1980b), subjects learned about food chains from a short text. One group was also shown a diagram of a typical food chain that had been constructed to represent conceptual distances as physical distances on the page. For example, hawks were placed closer to mice than to plants because in a food chain they eat mice not plants. It was found that the addition of the diagram to the text helped high ability learners but did not help those of lower ability. One interpretation of these data is that high ability learners were able to employ the diagram in a spatial processing strategy, which enabled them to organize the material more effectively, while low ability learners were unable to see the connection between the diagram and a useful learning strategy they might employ to good effect.

This conclusion leads directly to the consideration of metacognition and learning from spatial media. Metacognition involves the processes whereby decisions are made by learners about which strategies to use (see Gagne, 1977; Lawson, 1980). In a study (Winn, 1982d) which used tasks similar to the sequence and pattern recall tasks described above (but using letters only), one group of subjects was given instruction in the use of simultaneous and successive learning strategies and was told which of the two tasks (recall pattern of letters or letter sequence) to perform before each trial. A second group was not given instruction in strategies, and a third group was not told which of the two tasks to perform until after the sets of stimuli had been presented. In this way, learning strategy and knowledge of the task were varied. It was found that subjects who had been taught learning strategies performed better than those who had simply been told which task to perform, while the latter in turn performed better than subjects who did not have knowledge of the task until after the materials had been presented. Aptitude-treatment interactions were found showing that for both simultaneous and successive tasks, knowledge of task improved the performance of high ability learners relative to their performance when knowledge of task was

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withheld until after the stimuli had been presented. However, unlike with high ability learners, knowledge of task alone was not sufficient to improve the performance of low ability learners. These performed significantly better only if they had been given instruction in an appropriate learning strategy.

These results suggest two things. First, simultaneous and successive learning strategies can be taught to learners with the result that their processing of information in spatial media improves. Second, provided they know what the task is, high ability learners are able to decide on an appropriate learning strategy for themselves, while low ability learners need to be taught the strategy and when to use it. This conclusion is consistent with Bovy's (1981) theory, which relates learning strategies and mental ability. Generally, high ability learners can make better metacognitive decisions than learners of low ability.

Relevance to educational technology

Educational technology is concerned with the application of knowledge to the practical tasks of education (AECT, 1977). One ramification of this is that educational technology is concerned with design in the precise sense that the term is used by Simon (1969) to indicate a "linking science" between theory and practice. The design and development of instruction are therefore both central to educational technology and involve procedure for applying theory to practical problems.

Much of the theory that enables instructional designers to make useful practical decisions has been derived from research into learning and instruction. In particular, a great deal of this research has had to do with the ways in which information is presented to learners, cognitive processes, learner ability and learning tasks (see Bransford, 1979, pp. 6-9). This is precisely where the research described fits in. In "optimizing alternatives" (Simon, 1969), instructional designers must consider all forms of media, learners of all levels of ability, and all types of potentially useful learning strategies. Spatial media, simultaneous and successive processes, and the learning strategies that have been described will all at some time or another become grist to the instructional designer's mill.

There are as well more specific ways in which this research is relevant to instructional designs. When preparing spatial media (diagrams, for instance), the designer should not use highly meaningful elements if the intention is to show how the elements are related to each other. In extracting meaning from the elements, learners will find it more difficult to synthesize all the elements into the intended aggregate. Making elements contiguous (by linking them with lines, perhaps) might improve learners' ability to discern how the elements are related to each other. Designers should not allow spatial media to violate the left to right, top to bottom convention, particularly with learners who are low spatial and linear processors. Designers can use spatial media to make conceptual relationships explicit. However, only high ability learners are likely to use such representations unprompted. But designers can build instruction in relevant learning strategies into instructional materials, particularly when they are going to be used by low ability learners. This plan will overcome low ability learners' difficulty in selecting appropriate strategies for themselves.

These are just a few "design principles" that emerge from this selection of research on spatial media. A list of principles specifically for the design of diagrams is provided by Winn and Holliday (1982), and other relevant principles are to be found among those given by Fleming and Levie (1978). It is to be hoped that future research will shed even more light on the interactions that exist among the codes of spatial media and cognition so that even more guidance can be furnished to instructional designers for their important task.

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