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MEMORY You frequently will hear people say "I have a terrible memory," or "I can remember faces but not names." Such statements imply that human memory is a single organ, like a heart or spleen, and that some people have a large memory while others may come equipped with a small one or a defective one. In fact, the term *memory* reflects a rather complex assortment of systems for knowing. Human memories include a vast amount of knowledge about ourselves and our world plus an extensive set of strategies for learning, retrieving, and using that knowledge. We are aware of some of these strategies, which are under conscious control. Many other procedures for processing information may occur without our awareness, however. They occur automatically, with little or no effort.

This vast store of what we know and the strategies for knowing are the *long-term memory*. We can only think about or attend to a small part of this long-term memory at one time. This active part of long-term memory is called *working memory*. The capacity of working memory corresponds to the amount of our memory and our environment that each of us can attend to at any given time.

Individual differences in memory that are important to learning appear to be confined to three areas: (1) limits on working-memory capacity, (2) strategies for learning, using, and retrieving information, and (3) domain-specific knowledge—relevant knowledge the learner already possesses. Working memory will be discussed in more detail than the other two. Then I will discuss the relative importance of all three areas to learning.

A MODEL OF WORKING MEMORY

Alan Baddeley has envisioned a multicomponent working memory with a limited amount of attentional resources to do mental work. This component, called the central executive, is an important source of individual differences in memory. Several methods can be used to code and maintain information in working memory. One method is to translate concepts to a verbal (phonological) form. Another is to convert the concepts to a visual/spatial form. For example, if I tell you to think of a dog and a cat, you might think of the words "dog" and "cat" and rehearse them repeatedly. You might, instead, make a mental picture of a dog and cat playing together. Probably other coding methods exist, but the majority of research studies concern the phonological and visual/spatial codes.

Individual differences exist in the extent to which people use these two codes, and those differences are important to learning. Children who do not use the phonological code are slower to learn to read and slower at acquiring vocabulary than children who do use this code (Baddeley, 1990). The visual/spatial code is important for tasks in which we must mentally move or transform one or more objects (Salthouse et al., 1990). For example, if you try to pack a large number of suitcases into a small car trunk, you are more likely to succeed if you use a spatial code to solve the problem.

Individual differences in the working-memory capacity of the central executive appear to be an important factor in learning and retrieval of information. Some have even argued that this aspect of working memory is the important mechanism responsible for general intelligence (Larson & Alderton, 1990).

Measurement of Working-Memory Capacity. Digit- and word-span tasks have been used since the 1800s as tests of individual differences in memory. Such tests distinguish the extremes of intelligence, for example, between retarded and normal individuals. Even a simple test like the digit span reflects, not just fixed capacities, but strategies of information processing that are the result of prior learning (Estes, 1982).

Over the range of normal intelligence, digit- and word-span tasks do not seem to tap that aspect of working-memory capacity important to most complex cognitive tasks. To measure working-memory capacity, we must measure the number of words or digits an individual can retain while being forced to attend to some other part of memory or the environment. Turner and Engle (1989) had subjects perform a variety of such tasks: In one task, subjects saw a set of simple arithmetic problems each of which was followed by a word or digit, for example, "Is $(3 \times 5) - 6 = 7$?" TABLE. Subjects saw sets of two to six problems, solved each one, and then tried to recall the words that followed the problems. Another task required subjects to read a set of sentences aloud and to recall the last word of each sentence. The number of words recalled was assumed to reflect the amount of information the subjects could keep active in memory while periodically shifting their attention to the problems in one task or the reading of the sentences in the other task. These measures of working-memory capacity consistently predict performance on important real-world cognitive tasks, such as those that are described below.

Role of Working-Memory Capacity in Educationally Relevant Cognitive Tasks.

Reading. When we read for comprehension, it is frequently necessary to keep facts or phrases in working memory for a period of time so that we can integrate them with new information. Individuals with high working-memory capacity are much better at retaining earlier information in working memory and integrating that information to aid comprehension. Measures of working-memory capacity reliably predict performance on reading comprehension tests (Daneman & Carpenter, 1983).

Following Directions. Being able to do something we have been shown or told how to do is an important aspect of everyday cognition. Most teachers assume that all children can easily follow such directions as "Take out your math book, turn to page 73, and do the even-numbered problems, except number 6." Some children may not be able to complete this assignment even if they were paying attention to the teacher. Individuals of all ages with high working-memory capacity are able to follow more complex directions because they can keep more information in working memory (Engle, Carullo, & Collins, 1991).

Spelling. Spelling, at least in the early stages of learning, is an activity that depends on the amount of information we can keep in working memory at one time. Individual differences in working-memory capacity are an important factor in some children's difficulty in learning to spell. This is true even when reading ability is controlled (Ormrod & Cochran, 1988).

Arithmetic. Working memory has been shown to be important in the solution of arithmetic problems (Hitch, 1978). While this suggests that arithmetic learning probably varies with individual differences in working-memory capacity, no studies on such a relationship have been reported.

Vocabulary Learning. We commonly learn a new word by encountering that word in a context defining its meaning. For example, suppose I am talking to a woman and I know that she just won the lottery. I can see a broad smile on her face, and she says "I feel euphoric!" If I have sufficient information about the events in working memory at the time the word *euphoric* occurs, I can deduce the meaning. If I do not have adequate information about the events active in memory when the word occurs, I may not be able to deduce the meaning. Just such a relationship has been found. Subjects with high working-memory capacity are better able than those with low capacity to deduce the meaning of very unusual words from a context (Daneman & Green, 1986).

Notetaking. Working-memory capacity is an important factor in whether students are good notetakers. Working-memory span predicts the number of words, complex propositions, and main ideas recorded in notes. In fact, working-memory capacity is a better predictor of notetaking ability than grade point average or scores on the American College Test (ACT), a standardized aptitude test (Kiewra & Benton, 1988).

Writing. Good writers hold more information in working memory and simultaneously manipulate that information more effectively and more rapidly than do poor writers. Thus, working-memory capacity is an essential distinction between good and poor writers (Benton et al., 1984).

Problem Solving. The overloading of working memory is the principal source of errors in many different types of problem solving. For example, the demands of working memory exert a strong influence on performance on problems involving number-series-completion, such as 2, 6, 10, ______ . This has also been found for number analogy problems, letter series completions, and geometric analogies (Holzman, Pellegrino, & Glaser, 1983). One reason that working-memory capacity is so important to complex problem solving is because we can keep only a limited number of alternative solutions in working memory at one time.

Complex Learning. Perhaps the most impressive demonstration of the role of individual differences in working-memory capacity on learning comes from studies of computer programming. Shute (1991) gave subjects an extensive battery of tests for both general abilities and specific information-processing abilities, such as working-memory capacity. Her 260 subjects then received a forty-hour computer-aided course on Pascal programming. The most important factor predicting who learned the most from the course was a set of tests measuring working-memory capacity, which was more predictive than general knowledge of how to solve algebra word problems. Similar work showed that working-memory capacity was predictive of how well children would learn the Logo programming language (Lehrer, Guckenberg, & Lee, 1988).

STRATEGIES

One important source of individual differences in memory is simply the strategies we possess to learn, retrieve, and use information. Some individuals are capable of remarkable feats of learning using strategies such as those described in popular books on memory (Lorayne & Lucas, 1974). When retarded children are taught to use the same strategies in a simple memory task that are used by normal children, they will recall information as well as the normal children do (Butterfield, 1981). Such training, however, appears to have limited value because when the task is changed, even slightly, the retarded children again show memory deficits—they do not transfer their training to new situations. Campione, Brown, and Ferrara (1982) have argued that knowing a strategy for performing a given task is not sufficient for intelligent behavior. Individuals must have a capacity for self-awareness, understand the limits of the memory system, know when a strategy would be effective, be able to monitor the effectiveness of that strategy, and change to another strategy if that one is ineffectual.

It is important to understand that strategies can be difficult to learn and to manage. Thus, strategy learning, like other types of learning, is affected by capacity limitations. For example, children with greater working-memory capacity are able to learn and use a strategy for forming images to learn sentences. Children with smaller working-memory capacities do not learn or use such a strategy (Cariglia-Bull & Pressley, 1990). Once a strategy is learned well enough that executing it takes little attention, the role of working-memory capacity is probably less important than the quality of the strategy.

DOMAIN-SPECIFIC KNOWLEDGE

One of the most important individual differences in memory is simply in what has been learned already. It is much easier to learn and remember something if we have a framework in which to embed that new knowledge. For example, Spilich et al. (1979) tested subjects who either knew a great deal or not very much about baseball. The subjects read a description of a half-inning of a baseball game and were later tested on their memory for the game. Those people who knew the most about baseball also learned the most. They recalled more about what they had read than did subjects who were ignorant about baseball.

An important example of the role of domain-specific knowledge and the use of strategies comes from work done by Ericsson and Staszewski (1989). They worked with a subject who developed the ability to recall perfectly a list of over 100 digits that had been presented at a 1-per-second rate. This incredible feat was possible because the subject used his vast knowledge of times associated with track events. He coded the digit times associated with various events and used a very specific learning strategy for grouping the digits in his memory in a way that could be easily retrieved later. This individual had the same limitations of working-memory capacity as do the rest of us, but he had learned to circumvent those limitations, at least in this specific task, by using his knowledge and strategies for learning and retrieval. When asked to remember a similarly presented list of letters, this subject was just as vulnerable to the limits of working memory as others and could recall only six to eight of the letters.

The relative importance of working-memory capacity and existing knowledge was studied by Kyllonen and Stephens (1990). They had Air Force recruits learn and use a variety of logic rules, such as those used in electronic circuits. A variety of tests were administered to test for individual differences in processing speed, working-memory capacity, general knowledge, and the ability to transform factual knowledge into effective problem-solving skill. The results indicated that the most important determinant of successful learning of a cognitive skill is working-memory capacity. Both initial learning of the rules and translating those rules into effective problem-solving procedures were determined by the working-memory capacity of the subjects.

CONCLUSION

There are three aspects of memory in which individual differences can play an important role in learning new material: (1) working-memory capacity; (2) strategies; and (3) domain-specific knowledge. Working-memory capacity has been shown to be important in many different kinds of complex learning, including much that is done in the classroom. Once we learn strategies for processing information and specific information about a topic, however, the limits of basic abilities, such as working-memory capacity, become less important. If we try to learn in a new domain, in a manner not conducive to the strategies we have learned, we quickly see that the importance of working-memory capacity reemerges.

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