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Prior Knowledge Occupies Cognitive Capacity in Chess Problem Solving, Reading, and Thinking

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Abstract

Prior knowledge was varied in problem solving, thinking, and reading tasks in three experiments. The hypothesis was that the prior knowledge used in a cognitive task uses capacity in the same limited capacity active processing system that is used to process the ongoing task. In a reading experiment, prior knowledge about a target page was manipulated by controlling the preceding pages. In an experiment dealing with problem solving in the context of a chess game, prior knowledge was controlled by comparing experts with novices. In a third study subjects thought about personality descriptions of persons and groups, and about women's fashions and football plays; it was assumed that persons have more prior knowledge concerning the personality of persons than the personality of groups, that women have more prior knowledge about women's fashions, and that men have more prior knowledge about football. In all experiments, use of cognitive capacity in task performance was observed with a secondary task technique.

The results of all three experiments were consistent with the hypothesis that prior knowledge uses capacity in the active processing system. The prior knowledge hypothesis is consistent with some aspects of current cognitive theory but not consistent with others. The results also suggest a fundamental and unexpected limit on the cognitive processing of experts.

Information processing theories of cognitive processing often assume that memories of prior experience are stored over the long term in a relatively inactive state. They also assume that the cognitive task that is undergoing processing at a particular time is being processed in an active processing system, which some models identify as a working memory or short term memory store. When stored prior knowledge is to be used in the performance of a particular cognitive task, the prior knowledge is brought from the inactive state into an active state. In this active state the prior knowledge can be effectively used in performing the ongoing cognitive task.

In the standard model (e.g., Atkinson & Shiffrin, 1968) this change of state of prior knowledge is usually represented in a flow chart as an arrow leading from a long term memory store (the inactive memory) to a short term or working memory (the active processing system). Other models of cognitive processing include a similar assumption; although the metaphor of a spatial transfer of information is not always used, some change in the state of activation of the prior knowledge is expressed with other metaphors.

The active processing system is widely believed to be limited in capacity (Broadbent, 1958, 1971; Navon & Gopher, 1979; Norman & Bobrow, 1975; Posner, 1978). If the active system is limited in capacity, then it is plausible to deduce that any prior knowledge that is active in it will use some of the limited capacity. This paper reports three tests of the hypothesis that the prior knowledge used in an ongoing task uses cognitive capacity in the same active processing system that is used to perform the ongoing task. This will be referred to as the prior knowledge hypothesis.

The prior knowledge hypothesis has not been included conventionally among the explicit assumptions of cognitive processing models. Perhaps this is because the standard model and related models have traditionally assumed a small limit on the capacity of short term memory, with estimates ranging from 2 chunks up to 20 (Lachman, Lachman & Butterfield, 1978). It appears that with even a 20 unit limit, a body of prior knowledge of a size or complexity that approached that limit -- for example, the chess knowledge of an expert chess player -- if transferred to a short term store, would occupy so much of it that little or no capacity would be left over for performing the ongoing cognitive task. The result would be error, delay or failure on the task. Cognitive psychologists may have believed that this outcome did not seem likely to occur, and so the prior knowledge hypothesis may not have seemed easily compatible with models that include a small limit on the capacity of the active processing system. Other cognitive models are less explicit about the capacity of the active processing system, so evidence that large bodies of activated prior knowledge use capacity would be less critical for them.

Because the hypothesis that prior knowledge uses capacity in the active processing system has not been prominent in cognitive theory, the consequences of it have not been thoroughly worked out, and some of them turn out to be interesting. One set of consequences is related to the use of cognitive capacity by persons who do or do not have prior knowledge about a particular cognitive task, i.e., experts and novices. The cognitive programs of experts and novices have been investigated by protocol analysis techniques (e.g., Ericsson & Simon, 1980), but these techniques do not provide data on capacity usage. In the present experiments the secondary task technique was used. This technique was designed to provide data on capacity usage. The prediction of the prior knowledge hypothesis is that experts will use more capacity than novices when they are performing cognitive tasks for which the experts have activated large amounts of prior knowledge. Apparently this prediction has not been tested previously. To test this prediction of the prior knowledge hypothesis, in two of the experiments reported here, 'experts' on chess, and on football, women's fashions and implicit personality theory were observed as they processed problems in their special topics and in topics in which they were not experts. Use of cognitive capacity was measured with a secondary task technique. In a third experiment, differences in prior knowledge about a text topic were induced in readers and the use of capacity was observed in reading later parts of the text.

Another interesting consequence of the prior knowledge hypothesis is that it suggests the existence of a potential limitation on the cognitive processing of experts. If an expert has an extremely large amount of activated prior knowledge for a particular task, the knowledge will presumably use a correspondingly large amount of capacity. If the prior knowledge uses enough capacity, the capacity available for the ongoing cognitive task will be reduced: this follows from the assumption of a limited capacity. A straightforward prediction is that the ongoing task will be performed more slowly by such an expert with a very large amount of prior knowledge than by a person with less prior knowledge (assuming the prior knowledge is adequate to perform the task). In extreme cases of prior knowledge, so much active capacity may be occupied that the expert may not be able to complete the cognitive task at all. Such an hypothesis could be used to account for: (1) the long periods of time taken by extremely knowledgeable experts to solve problems that are solvable in less time by somewhat less knowledgeable experts, (2) the decreases in scholarly productivity that are sometimes reported anecdotally when scholars reach extremely high levels of expert knowledge about their special subject, (3) the incubation effect in problem solving, in which problem solvers who take time off from a thoroughly studied problem, presumably allowing some prior knowledge to be deactivated, report that when they return to the problem, they have an increased chance of solution, (4) the reduction of usable cognitive capacity that may be associated with aging individuals, who presumably have large amounts of prior knowledge. A possible qualification of this extension of the prior knowledge hypothesis is that experts seem likely to be able to chunk their knowledge more efficiently than novices, and chunks would presumably occupy less capacity. But in a very high level chunk, the usable information may not be visible on the surface. In order to reach a level of information that actually can be used in the performance of the ongoing task, the chunk may have to be unpacked to the point where usable information is revealed (Estes, 1972; Johnson, 1972). The unpacking process may use additional capacity that the less expert can avoid. It should be noted that such extreme cases of prior knowledge were not included in the present studies. The levels of prior knowledge used in the present studies may be regarded as intermediate in size between the levels of novices and those of high level experts, and decreases in performance of the ongoing task were not expected.

It is well to state at the outset what conclusions can be drawn from the various possible outcomes of the tests proposed here. If the prior knowledge is not shown to use capacity, that is consistent with the hypothesis that the cognitive task is performed in one active system, and the prior knowledge is active in a quite different system that does not share capacity with the first. If prior knowledge is shown to use capacity, that is consistent with the hypothesis that both the cognitive task and the prior knowledge are using capacity in the same active processing system.

The results of all three experiments were that subjects took longer to react to secondary task probes in the high prior knowledge conditions. Thus, the results of these experiments were all consistent with the hypothesis that the prior knowledge that is used in an ongoing cognitive task occupies capacity in the same limited capacity system that is used to perform the cognitive task. There are several aspects of the cognitive handling of prior knowledge that may make use of capacity. First, the retrieval of the bodies of knowledge from inactive memory may use capacity. The retrieval process presumably includes both search and decision components. Such a retrieval process may only occur once, at the beginning of the involvement of prior knowledge in the ongoing task, or it may be going on more or less continuously during performance of the task. Multiple retrievals would use capacity over a longer span of time than would a single retrieval episode.

Second, once a particular body of knowledge has been confidently located, its change of state from an inactive to an active status may use capacity. Third, once that activation has occurred, the maintenance of the activated state may be necessary, at least if the active state has rapid decay properties like those of conventional short term stores. The maintenance may be continuous, it may be periodic, as if the activation is regularly 'refreshed,' or it may be intermittent and dependent on the time course of use of the knowledge in the task. Fourth, the elements of the activated body of knowledge themselves are likely to occupy capacity, and the more extensive the knowledge is, the more elements it has, and the more capacity it can be expected to occupy.

Finally, the use of prior knowledge in the performance of the cognitive task may require additional cognitive operations that use capacity. These may involve the unpacking of chunks, searches through them, and decision processes associated with their use in the ongoing task. Or the prior knowledge may be in the form of programs of cognitive operations that are to be carried out as part of the cognitive task. Such programs enable additional operations, and these may use capacity.

The results reported here clarify the interpretation of some previous research on the use of cognitive capacity in reading. In a series of investigations of the influence of text characteristics on the use of cognitive capacity in reading, it was found that easy passages used more capacity than difficult ones (Britton, Westbrook, & Holdredge, 1978), where ease and difficulty were defined by cloze tests and ratings. This finding has been replicated (Britton, 1980; Britton, Zeigler. & Westbrook, 1980). It has been pointed out by Anderson and Armbuster (in press) that the easy passages used in those studies were about topics for which readers are "more apt to have available schemata or perspectives . . . than are those from the difficult passages." (p. 15). This interpretation is similar to the notion, based on the present results, that the readers had prior knowledge about the easy passages. The results of Britton, Graesser, Glynn, Hamilton, and Penland (in press) on genre differences can be interpreted along the same lines, as can the results of Britton, Westbrook, Holdredge and Curry (1979) that passages with more discourse level meaning (but identical to passages with less discourse level meaning) used more capacity.

Some limitations of these conclusions should be noted. First, they may only apply to complex bodies of prior knowledge, and probably not to isolated individual units. For such units, the retrieval, activation, maintenance and use of the knowledge may require so few cognitive operations that no observable capacity is used. Also, if the use of the prior knowledge is very highly practiced it may use less capacity (Shiffrin & Schneider, 1977; Schneider & Shiffrin, 1977).

Second, there appears to be a special case of combinations of prior knowledge and cognitive task for which prior knowledge will probably reduce use of capacity. These are tasks for which the completed solution of the task is already stored in memory and is easily accessible. For example, if the subject is asked to multiply 37 x 8, many mental operations will be carried out to arrive at the correct answer of 296. But if the subject is immediately asked again to multiply 37 x 8, the prior knowledge of the answer will be retrieved from memory, and the effect will be to reduce the number of mental operations and so the use of capacity.