Domain-specific Knowledge and Memory Performance (*)

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Since the late seventies, there has been increasing evidence for the striking effects of domain-specific knowledge on performance in various problem solving tasks. The focus in this paper will be on memory development. In numerous studies conducted in this field, it has been shown that domain/specific knowledge influences how much as well as what children recall. Research has further indicated that age-related differences in measures of basic memory capacities and strategies may be due to changes in the structure of domain-specific knowledge (cf. Bjorklund, 1987; Chi & Ceci, 1987; Ornstein & Naus, 1985; Siegler, 1986). While there is broad agreement that domain knowledge does have a strong impact on performance in various memory tasks, it is less clear how domain knowledge relates to achievement, and how this relationship changes with age and type of memory task.

In this paper, an attempt is made to further elaborate these issues. First, different ways or mechanisms through which domain-specific knowledge relates to strategy use in memory tasks will be briefly summarized. Next, empirical evidence indicating *direct* effects of the knowledge base on memory performance will be discussed in more detail. Here, the core assumption is that developmental improvements in memory performance will be discussed in more detail. Here, the core assumption is that developmental improvements in memory performance may be due to development and application of the knowledge base predominantly rather than to development of strategic competence. Research based on the expert-novice-paradigm seems particularly suited to illustrate this point and will receive special attention. The focus will be on developmental studies concentrating on the influence of a highly articulated knowledge base on memory performance. Empirical findings based on the expert-novice-paradigm will be used to (1) compare the Knowledge structure and memory performance of experts and novices of different ages, (2) to compare the knowledge representation of younger and older experts, and (3) to explore how individual differences in general intellectual abilities relate to the acquisition and use of domain-specific knowledge.

1. EFFECTS OF DOMAIN-SPECIFIC KNOWLEDGE ON MEMORY STRATEGIES

Contemporary research on the interaction of domain-specific knowledge and specific strategies indicates that there are at least three ways that the knowledge base relates to strategy

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use (cf. Pressley, Borkowski, & Schneider, 1987, 1990): knowledge can either facilitate the use of particular strategies, generalize strategy use to related domains, or even diminish the need for strategy activation. Developmental evidence for the various interrelationship between domain-specific knowledge and strategy use in children will be given next.

2. KNOWLEDGE ENABLES USE OF PARTICULAR STRATEGIES

The assumption that high knowledge enables high strategy use has been investigated in numerous investigations (see Bjorklund, 1987; Ornstein & Naus, 1985; Schneider & Pressley, 1989, for reviews). Most of these studies focussed on the effects of conceptual or semantic knowledge on the use of organizational strategies in sort-recall tasks. Experimental manipulations concerned children's knowledge of categorical relations among items in terms of *category typicality* (e.g.,Bjorklund, 1988; Corsale & Ornstein, 1980; Hasselhorn, 1990; Rabinowitz, 1984, 1988) or *interitem associativity* (e.g., Bjorklund & Jacobs, 1985; Frankel & Rollins, 1985, Schneider, 1986).

Research by Rabinowitz (1984) provides a good example of the relationship between category typicality and strategy use. Second and fifth graders were presented with lists of highly typical (e.g., *cat, horse*) or moderately typical (e.g., *fox, goat*) category exemplars for free recall. Subjects were given one of three learning instructions, either (1) no instruction, (2) repetition of individual items, or (3) grouping by categories. The categorization instruction was made particularly easy to execute because categorization subjects were given the list items blocked by category. Items were not blocked for repetition and no strategy subjects. Rabinowitz reported that differences in recall between the categorization subjects and the two other groups were greater (in favor of the categorization subjects) for the highly typical than the moderately typical list items. Regardless of age group, subjects were better able to take advantage of categorical instructions to benefit recall for the highly typical items.

The finding that the efficiency of the organizational strategy varies with the learner's knowledge base was also supported in a later experiment by Bjorklund (1988) which assessed children's acquisition and generalization of an organizational strategy for sets of typical and atypical items over repeated trials. As in previous research, greater levels of clustering and recall were found for the lists of typical than atypical items, with age differences being more apparent for the atypical items.

Other research has examined developmental differences in the use of organizational strategies when list items can be related on the basis of both categorical *and* associative relations. For example, Frankel and Rollins (1985) assessed the impact of associative versus categorical relations by factorially manipulating high and low category relatedness and high and low interitem associations. They found that fourth and tenth graders showed rather high levels of organization in recall whenever category typicality or associative strength were high. In contrast, kindergartners displayed greater category clustering only under conditions of associative interitem strength.

Schneider (1986) used a similar experimental design with German second and fourth graders. The results of this study are given in table 1. In general, more clustering was found for the highly associated lists, and the fourth graders had higher levels of recall and clustering and sorted items according to semantic categories to a greater degree than the second graders. Most importantly, there was a striking age-by-list associativity especially penalized the younger children. Using the relationship between clustering and recall as an indication of strategic processing, only the oldest children could be considered to be strategic in Schneider's study (see Bjorklund & Jacobs, 1985; Frankel & Rollins, 1985, and Hasselhorn, 1990, for similar evidence).

Taken together, this research clearly demonstrates that differences in the meaningfulness of words considerably influences strategic processing. Strategic effects of the knowledge base are not restricted to categorization tasks but have been observed in other memory paradigms as well (cf. Muir-Broaddus & Bjorklund, 1990; Pressley et al., 1987).

TABLE 1

Mean recall, category clustering during sorting and during recall as a function of grade, category relatedness, and interitem association (from Schneider, 1986)

Grade and task	High associativity		Low associativity	
	High Relatedness	Low Relatedness	High Relatedness	Low Relatedness
Grade 2				
Recall	12.37	10.44	10.75	10.88
Clustering/sorting	.38	.32	.35	.13
Clustering/recall	.63	.38	.18	.16
Grade 4				
Recall	17.31	15.37	14.19	11.50
Clustering/sorting	.70	.77	.40	.20
Clustering/recall	.70	.57	.56	.52

3. KNOWLEDGE GENERALIZES STRATEGY USE TO RELATED DOMAINS

For the sake of simplicity, examples illustrating knowledge effects of this sort will again be taken from studies dealing with organizational strategies.

Bjorklund and his colleagues (e.g., Bjorklund, 1987; Bjorklund & Jacobs, 1985) have proposed that semantic organization initially seen in the recall of young school children is mediated not by a deliberately imposed strategy but by the relatively automatic activitation of well-established semantic memory relations. As they automatically process higly related items in a categorical fashion, some children may notice categorical relations in their recall, and may then realize that categorization is a good learning technique. Hence, they initiate categorization strategies even when materials are not highly related.

Best and Ornstein (1986) presented data consistent with the interpretation that processing of highly associative, categorizable materials can lead to more complete semantic processing of nonassociated categorizable materials. Third graders learned a list of items with strong categorical interrelationships. After learning this list of highly related materials, the transfer of categorization to materials that did not contain obvious relationships was tested. Best and Ornstein were able to show that automatic categorization during processing of the first list induced categorization strategies with materials that would ordinarily not be processed categorically by third graders. See Bjorklund and Jacobs (1985) for another example of this generalization effect.

The findings reported by Best and Ornstein (1986) and Bjorklund and Jacobs (1985) support the hypothesis that there is a carry-over from processing of materials that «elicit» more sophisticated processing because of their compatibility with elements that are readily accessible in the knowledge base, to materials that are not so obviously consistent with prior knowledge. How to explain such carry-over effects? Bjorklund (1985, 1987) refers to the process of *reflective abstraction* when discussing this phenomenon. At some point in development, children are able to reflect upon the outcomes of their own cognitions, and to examine the products of their recall efforts. In this process, they may recognize previously unnoticed relations among the recalled items. Such carry-over experiences presumably can have a long-term impact, and are believed to be critical in the development of strategy use (see also Ornstein, Baker-Ward & Naus, 1988). Apparently the deliberate activation of category knowledge as a retrieval strategy does not occur before the late elementary school years (cf. Bjorklund, Muir-Broaddus & Schneider, 1990; Hasselhorn, 1990; Schneider, 1986).

4. NONSTRATEGIC EFFECTS OF THE KNOWLEDGE BASE

There is also evidence in the literature that many instances of efficient learning occur without strategic assistance, and that rich domain-specific knowledge can diminish the need for strategy activation (Bjorklund, 1985; Chi, 1985; Rabinowitz & Chi, 1987).

The class recall task developed by Bjorklund and his colleagues (Bjorklund & Zeman, 1982, 1983; Bjorklund & Bjorklund, 1985) seems well suited to illustrate nonstrategic effects of the knowledge base. For instance, Bjorklund and Zeman presented 7-, 9-, and 11-year-old children with two structurally similar memory tasks. The children were supposed to (1) remember the names of their classmates (class recall task), and (2) memorize and recall a list of taxonomically clusterable items. Although the usual age differences in recall and clustering were found in the traditional list learning task, children of all ages could remember the names of their classmates equally well. Furthermore, the cluster scores computed for seating arrangements, reading groups, and sex were comparable across age groups, whereas the cluster scores calculated for the free recall task differed as a function of age. In a follow-up study (Bjorklund & Bjorklund, 1985), subjects were instructed to use a specific retrieval strategy (i.e., use seat arrangements to mediate recall) in the class recall task. Although clustering values were positively affected by use of this strategy, there was no improvement in level of recall as a function of use of the strategy. These findings suggest that when knowledge base is sufficiently comprehensive, activation of its contents can become primarily automatic as is hypothesized to be for associative knwledge. In such a case, the employment of intentional memory strategies only has a minimal effect on memory performance.

The finding that rich domain knowledge sometimes eliminates the need to be strategic is not restricted to episodic memory tasks but can be generalized to other cognitive domains. For example, Siegler (1988) studied children solving math problems by retrieving math facts from their knowledge base rather than relying on computational strategies. According to Siegler, strategies were only used if the child had not previously stored a relevant math fact in long-term memory (or if the child was something of a perfectionist and wanted to ensure the fact stored in long-term memory was correct). In general, automatic fact retrieval was observed for comparably easy problems, whereas slow «backup» strategies were preferred in case of more difficult math problems (Siegler, 1990).

One conclusion from these findings is that the likelihood of monstrategic effects of knowledge increases with increasing richness of the knowledge base. Accordingly, nonstrategic effects of the knowledge base on cognitive performance should be the rule rather than the exception when the subjects possess high levels of expertise in the area under study. In the remainder of this paper, findings from developmental studies contrasting experts and novices will be discussed in more detail. Developmental studies using the expert-novice paradigm allow for a relatively unbiased estimate of how greatly domain-specific knowledge influences memory performance because chronological age and the degree of expertise are not necessarily confounded. A second advantage of developmental studies using child experts and novices is that differences in the structure of experts' and novices' knowledge representations can be compared for different age groups. Assuming that developmental differences in cognitive performance may be accounted for, at least in part, by differences in domain-specific knowledge, the issue of how the structure of expertise changes with age seems particularly important.

5. EXPERTISE AND COGNITIVE PERFORMANCE

5.1. *Effects of expertise on how much is remembered*

Thus far, studies using the expert-novice paradigm have yielded impressive evidence for the important role of domain-specific knowledge in memory performance. Perhaps the most robust finding in the literature on knowledge effects is that experts in an area learn more when studying new information in their domain of expertise than do novices in that domain (cf. Schneider, Korkel & Weinert, 1990; Voss, Fincher-Kiefer, Greene & Post, 1986, for reviews). The first striking developmental data consistent with this conclusion was presented in a now classic study by Chi (1978).

Chi recruited experienced and unexperienced chess players and gave them the task of recalling various chess positions presented to them briefly. The most interesting aspect of this study was that subjects' knowledge correlated negatively with age — the children (average age = 10 years) were the experts, and the adults were the novices. Although the children performed worse on traditional memory-span tests than the adults, they averaged much better on the chess-related memory tasks. They were able to remember more chess pieces correctly, needed fewer trials to reach the learning criteria, and predicted their performance more accurately. The study provided evidence supporting the ideia that domain-specific knowledge enables a child expert to perform much like an adult expert and better than an adulte novice, thus showing a reversal of usual developmental trends.

Chi (1978) has stimulated follow-up studies. One study carried out in our lab (Gruber, Gold, Opwis & Schneider, 1989; Opwis, Gold, Gruber & Schneider, 1990) aimed at replicating and extending Chi's study on chess expertise. While Chi's study was based on a rather small number of subjects and did only comparate two groups (i.e., child experts and adult novices), all four possible combinations of groups were considered in our study. that is, both child novices and experts (20 subjects per group) participated in the study. Chess experts were selected according to their performance in a test assessing procedural chess knowledge (the Knight' Tour task) and in most cases had official chess ratings and experience in chess competitions. Subjects classified as novices were either beginners or did only play occasionally. Children's ages ranged from 11 to 13 years, with a mean of about 12 years. The adult subjects were university students and faculty members (average age = 26 years).

Subjects were presented four tasks. The first was similar to that use by Chi and required the immediate, delayed and repeated recall of two meaningful chess positions. In a second task, subjects had to reconstruct a random chess position. The third task required subjects to recall two positions in a control setting: wooden pieces were located on a wooden board that had not squares but a mixture of triangles, rectangles, and circles on it. The number and form of wooden pieces equated that of the chess pieces in the chess tasks. Finally, subjects were presented with a digit-span task similar to that used by Chi (1978).

The major results are given in Table 2. They show that effects of expertise varied as a function of memory task. Significant effects of expertise could be demonstrated for recall of meaningful chess positions, regardless whether immediate, repeated, or delayed recall was concerned. There were no effects of age, and no significant interactions. As expected, the results for immediate recall of the random chess position was less impressive: only difference between child experts and adult novices turned out to be statistically significant. There were no significant effects of expertise and age on immediate recall of wooden pieces in the control task. Finally, Chi's finding that adults remembered more than children in the standard digit-span task was replicated in our experiment. There were no effects of expertise, and no significant interactions.

Taken together, the results of this study not only replicate basic findings of Chis's study but seems also suited to identify various knowledge components (i.e., familiarity with materials, familiarity with spatial arrangements,familiarity with contents) thal all contribute to the experts' superior performance.

The reversal of the usual age effect is not

TABLE 2

Mean number of items recalled in the chess and control tasks (standard deviations are in parentheses; Data from Opwis et al., 1990)

Variable	Children Novices	Children Experts	Adults Novices	Adults Experts
(1) Meaningful chess position				
Immediate Recall	4.95 (1.68)	8.78 (2.92)	4.58 (1.43)	7.10 (2.52)
Repeated Recall	15.90 (3.80)	19.52 (3.02)	15.28 (4.47)	20.85 (1.91)
Delayed Recall	4.95 (4.36)	11.20 (6.32)	4.20 (4.53)	11.35 (8.00)
(2) Random chess position				
Immediate Recall	3.25 (1.92)	5.00 (2.20)	2.70 (1.63)	3.60 (2.04)
Repeated Recall	12.80 (3.86)	17.25 (4.42)	10.40 (4.37)	15.80 (4.07)
(3) Control Task				
Immediate Recall	2.55 (0.99)	3.33 (0.88)	3.00 (1.29)	3.15 (1.13)
Repeated Recall	8.65 (2.97)	11.33 (4.12)	10.65 (3.66)	13.33 (3.41)
(4) Memory Span	5.75 (0.97)	6.25 (1.02)	7.05 (1.32)	7.65 (0.93)

restricted to memory for chess but can also be demonstrated for text learning. In another developmental study conducted in our lab (Schneider, Korkel & Weinert, 1989), third-, fifth-, and seventh graders were presented a story about a soccer game, with the participants classifiable as soccer experts and novices. The expected differences between experts and novices were especially evident in the recall and comprehension of the soccer-related passage. In general, older children outperformed younger children, and experts were significantly better than novices at each age level. The findings confirmed Chi's results in that a reversal of developmental trends was demonstrated: third grade experts recalled significantly more text units than both fifth and seventh grade novices. Thus, this study again demonstrated how greatly domain-specific knowledge can influence memory performance.

6. EFFECTS OF EXPERTISE ON HOW AND WHAT IS REMEMBERED

As emphasized by Ornstein and Naus (1985), an association between expert/novice status in a particular area and differential patterns of recall of this material does not constitute an explanation of how such differences arise. The sheer quantity of knowledge is not nearly as important as how that knowledge is structured or represented, how the structure of knowledge representations changes with age, and how the structure affects processing performance (cf. Chi & Ceci, 1987).

Although there are still great debates about the modes of representations in the knowledge base, there seems to be basic agreement that modified network models of semantic memory are suited to describe the representation of declarative knowledge, assuming that every item or concept in semantic memory is represented by nodes that are connected to many others by means of links. However, a variety of views exist as to how knowledge structure develops or changes with expertise.

For example, Gobbo and Chi (1986) inferred from their analysis of children's production protocols that dinosaur experts' knowledge strutures are more integrated and cohesive, more differentiated and complete than those of dinosaur novices. Thus the knowledge structures differed mainly in terms of *quantity of knowledge*: with increasing expertise, information stored in the knowledge base gets more accessible because the number of concepts as well as the number of attributes related to each concept increase, and because there are more links among the concepts and the attributes that children already have.

On the other hand, there is also evidence that experts and novices differ *qualitatively* in the way their knowledge is represented. For example, Means and Voss (1985) found qualitative differences between «Star Wars» experts and novices that concerned hierarchical development: Experts differed from novices in that they constructed a more complete hierarchical structure of «Star Wars» containing high-level goals, subgoals, and basic actions. Even more interestingly, there were age-related representational differences within the sample of «Star Wars» experts. While the older experts seemed to interpret «Star Wars» in relation to an «international conflict» schema involving interrelated political-moral-military components, the younger experts tended to interpret «Star Wars» in reference to a military-oriented «good guy — bad guy» schema.

Another qualitative difference between experts and novices found in studies on chess expertise concerns the way stimulus materials are *reorganized* or *recoded* (cf. Chase & Simon, 1973; de Groot, 1965). Splitting a chess position into meaningful patterns (semantic units or «chunks») reduces its complexity. Chase and Simon (1978) found that better players recalled more chunks and more pieces per chunk on the first recall trial when chunks were partitioned by an interresponse latency of greater than 2 sec. Using a similar partitioning technique, Chi (1978) found that her child experts formed significantly larger chunks than the adult novice on the first trial. In our replication of Chi's study, we did not find different chunk sizes for our child experts and novices when data were analyzed using the interresponse latency partitioning technique. However, significant differences between experts and novices resulted when a technique developed by Bratko, Tancig and Tancig (1986) focusing on piece relations was used to assess «chunking» at the first recall trial: as indicated by a «collective reconstruction» coefficient, most experts not only preferred a similar sequence of pieces when reconstructing the chess position, but also created similar patterns: Most of these patterns were «colectively reconstructed» by at least 50% of the experts. There were no similar effects for the novices, indicating that novices did not represent common or stereotyped features of the chess position in the same way experts do.

Our reanalysis of the study on soccer expertise also revealed qualitative differences in the way the soccer-related passage was recalled (Korkel & Schneider, 1989). For example, experts and novices differed considerably in the importance ratings given to individual parts of the text. The youngest experts were clearly superior to the oldest novices in recognizing the important compared to the less important aspects of the text. Comparisons within the sample of experts revealed that the recall patterns of seventh grade experts differed qualitatively from those obtained for the two younger groups in that the mean proportion of recall decreased almost linearly with decreasing importance level (cf. Figure 1). As can be seen from Figure 1, the pattern observed for the two younger groups did not show the same linear trend although the most important information was recalled best. Recall patterns of all expert groups clearly differed from that of soccer novices who recalled as much important as unimportant text information, regardless of age.

Taken together, the findings summarized in this section indicate that developmental changes in the structure of domain-specific knowledge may take different forms in different areas. The development of knowledge strutctures remain debatable as several data sets may fit one or many of the views summarized above (McPherson & Thomas, 1989). However, there seems basic agreement that it is not only *quantity* but also *quality* of knowledge that distinguishes experts from novices, regardless of age.

7. INTELLIGENCE, KNOWLEDGE AND MEMORY PERFORMANCE

Individual differences in intelligence continue to be the best predictor of academic sucess. However, recent research has indicated that differences on cognitive tasks as a function of intelligence can be eliminated or greatly minimized by controlling individual differences in domain-specific knowledge.

The assumption that domain-specific expertise can compensate for low overall ability on domain-related cognitive processing tasks was first confirmed in studies that focused on adult population. For example, Ceci and Liker (1986) demonstrated that adults who appeared to be operating at low levels of intellectual functioning (e.g., IQs in the 80s) were capable of complex classification and reasoning processes when the stimuli were highly familiar. Walker (1987) compared high- and low-aptitude adults who were either baseball experts or novices. When presented with a baseball text passage, low-aptitude/high-knowledge subjects recalled more information than high-aptitude/low-knowledge subjects.

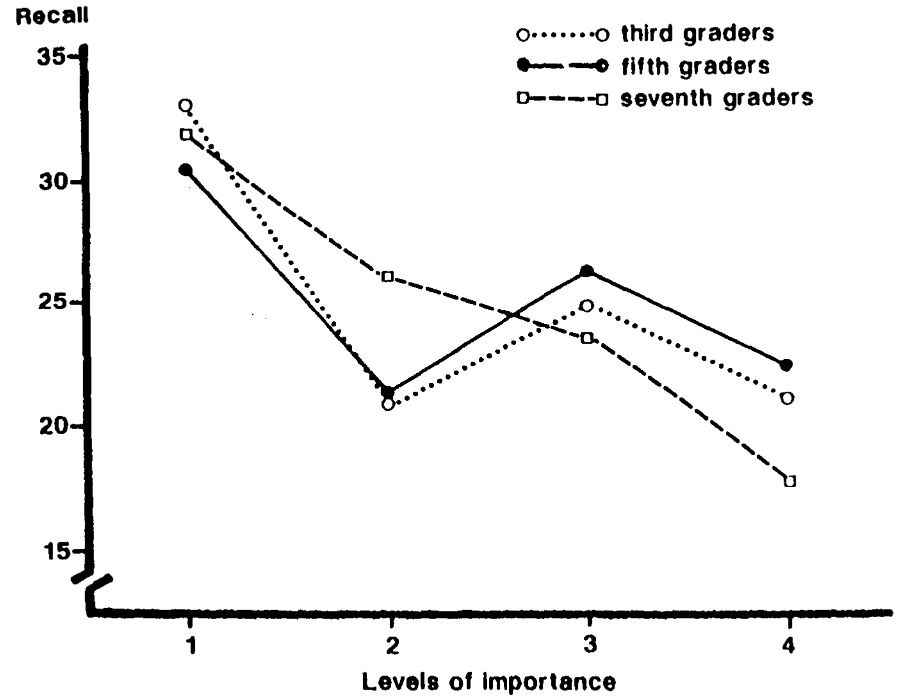
Results from our lab (Schneider et al., 1989, 1990) indicate that this pattern of findings can also be generalized to child populations. When we divided our samples of soccer experts and novices into subgroups of high- and low-aptitude children, we did not find an aptitude effect on text recall or comprehension, nor were there any significant interactions. At each level of expertise, higher IQ children did not remember more than lower IQ children, nor were they more likely to draw correct inferences or to notice inconsistencies within the story. This finding proved to be stable over time: when the same subjects were retested one year later, neither effects for intelligence nor any significant interactions were found (Schneider & Körkel, 1989).

Additional confirmation for the validity of our results for the area of text processing was provided by Recht and Leslie (1988) who investigated how domain-specific knowledge influences recall and comprehension of high-knowledge versus low-knowledge children differing in reading ability. As might be expected, children with greater knowledge of baseball recalled more information from a baseball text passage than did children with less knowledge. More interestingly, there was no effect of reading ability, and no significant interaction between reading ability and domain-specific knowledge. As emphasis by Recht and Leslie, students with high reading ability but low knowledge of baseball were no more capable of recall or summarization than were students with low reading ability and low knowledge of baseball.

Further evidence confirming these results comes from our chess study (Gruber et al., 1989). We found that while chronological age and academic achievement predicted novices'

FIGURE 1

Mean Proportion of text units recalled by soccer experts as a function of age and importance level (from Körkel & Schneider, 1989)



and academic achievement predicted novices' recall of meaningful chess positions, individual differences in these two variables were irrelevant with regard to child experts' recall of chess positions. For the latter group, the only significant predictor accounting for almost 40% of recall variance was the duration and intensity of practice reported by the children.

Taken together, all these studies confirm the assumption that rich domain-specific knowledge can compensate for low overall aptitude on domain-related cognitive tasks.

8. CONCLUDING REMARKS

In their impressive review of the literature dealing with the role of content knowledge in memory development, Chi and Ceci (1987) found it necessary to create an imbalance, that is, to omit studies from their review that conceived of strategies and metaknowledge as the basic motors of memory development. The results of the numerous studies dealing with the effects of domain-specific knowledge on memory performance summarized in this paper let me believe that such a review strategy is no longer needed. Although I do not want to create the impression that changes in domain-specific knowledge are the sole source of developmental differences in memory, the findings clearly indicate that the knowledge base exerts a powerful influence on strategy use and performance in several memory paradigms.

Having detailed knowledge for a domain permits children to process and remember domain-specific information more efficiently, apply strategies more effectively, and to integrate novel information more easily than domains for which they have less detailed knowledge. Domain-specific knowledge contributes considerably to the development of other competencies that have been conceived of sources of memory development, such as basic capacities, strategies, and metamemory. If the knowledge base is particularly rich — as in the case of expertise — it exerts a greater influence than all other factors combined, outweighing the other memory advantages of adults (Chi, 1978) or more intelligent children (Schneider et al., 1989).

Although there is no doubt that changes in domain-specific knowledge play a large role in memory development, this does not imply that children's learning progress is always determined by individual differences in the knowledge base. Young children are novices in many domains, particularly in domains relevant for academic sucess. In the early school years, individual differences in intellectual abilities, basic memory capacities, general memory strategies, and metacognitive knowledge may influence memory performance even more than individual differences in the (scarce) knowledge base. Undoubtedly, the impact of domain-specific knowledge increases considerably over the school years. However, much remains to be learned about developmental changes in children's knowledge about school-related domains and changes in the way this knowledge helps children remember.

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