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Knowledge, Processing, and Working Memory: Implications for a Theory of Writing

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This article surveys writing research and attempts to sketch a principled account of how multiple sources of knowledge, stored in long-term memory, are coordinated during writing within the constraints of working memory. The concept of *long-term working memory* is applied to the development of writing expertise. Based on research reviewed, it is speculated that lack of fluent language generation processes constrains novice writers within short-term working memory capacity, whereas fluent encoding and extensive knowledge allow skilled writers to take advantage of long-term memory resources via long-term working memory.

Twenty years ago, Flower and Hayes (1980) offered as a metaphor of the writer the image of a busy switchboard operator who juggles multiple calls, makes connections, and solves problems while presenting an outward voice of composure and control. The metaphor was intended to illustrate the multitask nature of writing and the coordination of knowledge and processing during composition. Hayes and Flower's (1980) metaphor and the cognitive model of writing from which it derives have profoundly influenced psychological studies of writing in the intervening decades. Recently, Hayes (1996) offered a revised model that differs from the 1980 version in several ways, most notably in providing for more articulated sources of knowledge within long-term memory (LTM) and a more explicit role for working memory. Thus, the busy switchboard operator now holds a spot on center stage in the guise of working memory, and contributions of knowledge are explicit. Still lacking, despite the proliferation of writing research over the past 20 years, are detailed descriptions of how knowledge stored in LTM is accessed and used within a limited-capacity working memory.

In this article I attempt to sketch a developmental model of memory and writing processes, one that stresses the interactions between working memory and knowledge stored in LTM, as well as changes in such interactions as writing-relevant knowledge increases. I explore the concept of *long-term working memory* (LT-WM) developed by Ericsson and Kintsch (1995; Kintsch, 1998) and apply the concept to the development of writing expertise. I begin with a brief discussion of memory theory to provide a context for the discussion of LT-WM, which I then apply to the domain of writing. Although much relevant empirical research remains to be done, I speculate that writing expertise depends on the development of two things: fluent language generation processes and extensive knowledge relevant to writing (e.g., topic knowledge, genre knowledge). The former enable the developing writer to begin to manage the constraints imposed by short-term working memory (ST-WM), whereas the latter allows the writer to move beyond the constraints of ST-WM and take advantage of the resources of the LT-WM.

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ST-WM VERSUS LT-WM

Short-term memory (STM) was originally construed as a somewhat static buffer of seven plus or minus two storage units (Miller, 1956). STM contains the contents of consciousness that are the focus of current attention and are thereby distinct from the rest of knowledge stored in LTM. Empirical work by Baddeley (1986, 1998; Baddeley & Hitch, 1974) demonstrated the need for a more dynamic conceptualization of STM, one that Baddeley called *working memory*. Working memory, as described by Baddeley and others (Cantor & Engle, 1993; Daneman & Carpenter, 1980; Just & Carpenter, 1992; Swanson, 1992) incorporates both storage and processing constraints. Trade-offs exist between working memory's storage and processing functions because of resource limitations within the system. When more resources are devoted to

processing, fewer resources are available for storage. Conversely, when storage is privileged, processing can suffer.

Baddeley (1986) defined working memory as "the temporary storage of information that is being processed in any range of cognitive tasks" (p. 43). Kintsch (1998; Ericsson & Kintsch, 1995) argued, however, that the range of cognitive tasks encompassed by such a ST-WM model was limited to the types of arbitrary learning and superficial reasoning tasks that abound in laboratory studies. Such a model of ST-WM, according to Kintsch, could not account for the kinds of extensive reasoning and knowledge manipulation that characterize expertise in real-world cognitive tasks such as chess, medical diagnosis, and comprehension. Kintsch (1998) proposed an alternative account of the working memory employed in such real-world tasks, one he and Ericsson (Ericsson & Kintsch, 1995) called "long-term working memory." LT-WM contains not only the limited number of elements activated in ST-WM, but also retrieval structures that link STM items to related elements in LTM. The items already activated within the capacity-limited STM function as retrieval cues for those parts of LTM to which they connect. Thus, the information available in LT-WM is of two types: those items activated in ST-WM and those items in LTM that can be reached via the retrieval structures. Such LTM elements are not actually stored within working memory, but they can be quickly retrieved when processing requires (in about 400 ms, as estimated by Ericsson & Kintsch, 1995).

Unlike ST-WM, which has strict capacity limitations, the capacity of LT-WM is limited only by the nature of the encoding processes that build retrieval structures and by the extent of knowledge in LTM to which those structures connect. Kintsch (1998) argued that effective retrieval structures result from knowledge that is "strong, stable, well practiced, and automated, so that it can be employed for encoding without additional resource demands" (p. 242) and from encoding processes that are rapid and reliable. Such encoding processes are specific to particular knowledge domains. In the case of comprehension, Kintsch's primary focus, these encoding processes are the normal processes of skilled comprehension (e.g., word recognition, syntactic parsing). In the case of medical expertise, these encoding processes may relate to recognition of diagnostic patterns of symptoms. Thus, the resources of LT-WM are available only in domains of relative expertise. LT-WM is an emergent feature of cognition resulting from an extensive knowledge base and efficient task-specific processing.

From such an LT-WM perspective, the debate about the causal relation between processing and storage capacity in working memory becomes moot (see Ericsson & Kintsch, 1995; Kintsch, 1998). This debate has taken place largely within discussions of reading skill, and proponents of the capacity view argue that less-skilled readers have smaller working memory capacities that then constrain linguistic processes such as lexical access and syntactic parsing (Cantor & Engle, 1993; Just & Carpenter, 1992; Miyake, Just, & Carpenter, 1994; Swanson, 1992). Kintsch reinterpreted such findings, arguing that so-called high-span readers simply encode (i.e., comprehend) text more efficiently, build more effective retrieval structures, and thereby store more complete text representations in LTM to be retrieved as needed into LT-WM. Skilled readers thus have access to resources beyond the limits of ST-WM. As Kintsch (1998) explained, "it is not that good readers have a larger box to put things in for temporary storage, but that they are more skilled in putting things into long-term storage and retrieving them again" (pp. 239–240).

Kintsch and Ericsson (1995) argued that traditional working memory descriptions have difficulty accounting for a number of empirical findings, and central in Kintsch's (1998) discussion of comprehension were effects of interrupting comprehension. In a series of studies, Glanzer and his colleagues (Fischer & Glanzer, 1986; Glanzer, Dorfman, & Kaplan, 1981; Glanzer, Fischer, & Dorfman, 1984) compared comprehension of readers who read a normal eight-sentence text with the comprehension of readers who read the same text with unrelated sentences among each of the original eight. According to a traditional ST-WM account, processing the unrelated sentences would displace representations of the developing text from working memory and disrupt comprehension (see, e.g., the STM processing description in the model of Kintsch & van Dijk, 1978). In Glanzer's experiments, however, interruptions had no effect on comprehension, and the only effect was an increased reading time of approximately 400 ms after each interruption. By an LT-WM account, after each interruption, processing of the next related sentence provides cues to representations of prior text stored in LTM. A coherent text representation develops within LT-WM as retrieval structures (capitalizing on LTM knowledge of topic and text structures) provide ready access to previous text representations and link them to text elements currently being processed. Furthermore, just as LT-WM theory would predict, processing times were found to be longer still when the interrupted texts contained unfamiliar content and followed the format of technical reports (McNamara & Kintsch, 1996), thereby reducing the usefulness of LTM topic and genre knowledge.

WRITING ACQUISITION: KNOWLEDGE, PROCESSING, AND LT-WM

Working memory (most frequently cast within a more traditional ST-WM framework) has received considerable recent attention from writing researchers (Butterfield, Hacker, & Albertson, 1996; Kellogg, 1987, 1996; Levy & Ransdell, 1995; McCutchen, 1996; Ransdell & Levy, 1996). Writing research is replete with examples of process interactions and recursions, all of which must be orchestrated within some executive system. For example, data as diverse as protocols (Flower & Hayes, 1980, 1981, 1984; Hayes & Flower, 1980;

McCutchen, 1984, 1988), pause times (Matsuhashi, 1982), and keystrokes (Levy & Ransdell, 1995) indicate that skilled writers continually juggle knowledge and process.

This view of skilled writing, however, is quite at odds with the portrait of novice writers painted most vividly by Bereiter and Scardamalia (1987). For the novice, writing is less a juggling act and more a matter of simply getting ideas down on paper as they are retrieved from LTM. Such a streamlined process is the heart of the knowledge-telling strategy described by Bereiter and Scardamalia. Based on their observations of children's writing, Bereiter and Scardamalia inferred a writing process cued not by rich knowledge sources, but by the previous sentence or the writing prompt.

A theory of writing development should entail a principled account of how the novice writer gains expertise and should include an explanation of how multiple sources of knowledge, stored in LTM, are coordinated and used in various writing processes within the limits of a constrained working memory. The distinction between ST-WM and LT-WM provides the beginning of such a developmental account. I suggest that novice writers are indeed constrained by working memory limitations. Because they lack fluent text-generation processes and extensive writing-relevant knowledge, children are unable to deal with the multiple demands imposed by the writing processes described by Hayes and Flower (1980). Young writers, and less sophisticated writers in general (Daiute, 1981, 1984; Flower, 1979), are constrained by the limitations of ST-WM and therefore depend on alternative writing strategies, such as knowledge telling.

In contrast, skilled writers[1] possess fluent text-generation and transcription processes, as well as extensive knowledge about topics, text genre, and routines for coordinating writing processes. Such an assertion is much in line with the arguments put forth by Graham and Harris (2000) concerning the role of self-regulation and transcription skills in writing development. I wish to add to their argument a further assertion that such fluent encoding processes and rich knowledge bases enable skilled writers to move beyond the limits of ST-WM and capitalize on the resources of LT-WM.

NOVICE WRITERS AND ST-WM CONSTRAINTS

There exists abundant evidence that novice writers, especially young novices, are severely constrained by their lack of fluent encoding processes during writing (see Graham, Berninger, Abbott, Abbott, & Whitaker, 1997; Graham & Harris, 2000; McCutchen, 1996). I survey such research only briefly and relate it, when possible, to working memory issues. Such lower level skills, identified as transcription and text generation by Berninger and Swanson (1994), constitute the translating process described in the original Hayes and Flower (1980) model. Text generation is assumed to share many components with oral language generation, such as content selection, lexical retrieval, and syntactic processes. In contrast, transcription entails the cognitive and physical acts of forming *written* (as opposed to *spoken*) representations of text.

Transcription processes (notably spelling and handwriting) seem most limiting in the earliest stages of writing acquisition. For example, King and Rentel (1981) found clear quality and quantity differences favoring dictation over writing (i.e., text generation without vs. with added transcription demands) in a study of first- and second-grade children. Differences favoring dictation are more qualified for older children, however (Bereiter & Scardamalia, 1987; McCutchen, 1987). Bourdin and Fayol (1994) examined transcription processes within the explicit context of working memory. They varied response modality (spoken vs. written) in a serial recall task and found that recall was significantly poorer in the written condition for children but not for adults. They interpreted these findings as evidence that the transcription process of adults, but not children, was sufficiently fluent to operate with minimal working memory demands. Bourdin and Fayol then required adults to write in cursive uppercase letters, thereby preventing use of their overlearned, highly fluent transcription processes (and, I suggest, depriving them of access to LT-WM). In this condition, adults (when constrained by the limits of ST-WM) also showed poorer recall when writing. In a related series of experiments, Bourdin and Fayol (1993) changed the task from serial recall to sentence generation and again demonstrated that transcription imposed resource costs for children but not for adults. Thus, until transcription processes develop sufficient fluency, writers seem constrained by ST-WM limits.

Working memory has also been related to text generation and writing skill in a number of other tasks. Bereiter and Scardamalia (1987) found that children's ability to defend a thesis in an essay was related to the number of informational chunks they could coordinate within a single sentence (a combined span and text-generation task). Tetroe (1984; reported in Bereiter & Scardamalia, 1987) independently assessed children's working memory spans and examined each child's ability to honor multiple ending-sentence constraints. Tetroe saw a marked decrease in children's ability to honor ending-sentence constraints as the number of constraints exceeded the child's memory span. Similarly, McCutchen and Perfetti (1982) observed developmental differences in children's ability to honor multiple constraints in a writing task and explicitly modeled those differences in a computer simulation that varied the amount of information in working memory during each text-generation cycle. We argued that as children's

[1]In this context I use the terms *skilled writer* and *expert writer* interchangeably to denote the level of skill possessed by literate adults who express themselves well in writing. I do not reserve the term *expert* for such literary artists as described by Graham and Harris (2000).

language encoding developed fluency with age (an assumption supported by our finding that older children wrote both longer and more coherent texts), they were increasingly able to handle the memory requirements imposed by our writing task. Taken together, such studies support the importance of fluent text-generation processes in writing and suggest that without fluency writers cannot move beyond ST-WM limitations.

Although LT-WM was not explicitly discussed, McCutchen, Covill, Hoyne, and Mildes (1994) documented relations among text-generation processes, working memory, writing skill, and LTM knowledge. In that study, elementary and middle-school students wrote essays and participated in two working memory tasks, a reading span task, in which students read lists of sentences and recalled the final word in each sentence, and a speaking span task, in which students generated a sentence for each word on lists and recalled the words. Half of the students had no further task constraints; that is, they read and were free to generate sentences that were unrelated to one another. However, we imposed an additional discourse constraint on the remaining students, asking these students to read and generate brief stories. Thus, in the story condition, we permitted students to use their knowledge of narrative structures (stored in LTM) to augment their performance in the working memory task.

With no discourse constraints, we found that only speaking span correlated with writing skill. That is, without the benefit of LTM knowledge of narrative structures, fluency of text-generation processes (not text-comprehension processes) predicted writing skill. Under story constraints, however, both speaking span and reading span correlated significantly with writing skill, suggesting that better writers' access to narrative structures in LTM improved their performance in both the reading and the speaking span tasks. Most interesting, only the more skilled writers in the sample showed improved memory spans in the story condition. From an LT-WM perspective, these findings suggest that only the more skilled writers, with their more fluent text-generation processes, were able to use their narrative knowledge to tap LT-WM resources. Without fluent language encoding processes, the less-skilled writers remained constrained by ST-WM.

In the same study, we also examined the processing assumption more directly and documented that more skilled writers indeed process individual words more fluently. Using a lexical decision task, we found that skilled writers were both more rapid and more accurate in accessing individual words in memory. Additional evidence came from an analysis of the children's essays. Sentences written by skilled writers were longer than those by less-skilled writers, again suggesting more developed text-generation processes. Thus, the analysis of children's texts supported our interpretation of the memory data—skilled writers showed evidence of more fluent language encoding processes that enabled them to better cope with working memory constraints.

I recently reexamined the link between writing skill and encoding fluency, specifically transcription fluency (e.g., handwriting and spelling) in a study of first- and second-grade writers (McCutchen et al., in press). Children completed a battery of reading and writing assessments, as well as a composition task that was scored for overall narrative quality. I reasoned that inefficient handwriting processes should increase ST-WM demands during composing (see Bourdin & Fayol, 1994) and limit text quality. Similarly, if words' spellings were not stored as easily retrievable LTM knowledge, the construction of spellings online would also increase processing load and decrease text quality. In a regression analysis, reported here for the first time, I found that three transcription variables—number of sentences produced and speed of forming letters (two fluency measures) and spelling knowledge—combined to account for a significant portion of the variance in writing quality (R^2 = .61). Such findings replicate previous research (Berninger & Swanson, 1994) and suggest that fluent encoding processes improve the performance of novice writers when constrained by ST-WM and in some conditions (e.g., the story condition of McCutchen et al., 1994) help writers gain access to additional LT-WM resources.

Lack of fluency in language encoding processes is not confined to young writers. Relations between language encoding processes and writing skill have been reported for high school as well as college students (Benton, Kraft, Glover, & Plake, 1984). Older writers who lack fluency (sometimes referred to as "basic writers" in composition research) may continue to be constrained by ST-WM limitations. Daiute (1981, 1984) suggested that memory limitations make it difficult for basic writers to avoid (and later correct) certain grammatical errors, such as subject–verb agreement, because such structures become more difficult to coordinate as more words intervene between key constituents. She supported her assertion by documenting negative correlations between memory capacity (as measured by sentence recall) and the occurrence of errors in students' texts. In addition, Fayol, Largy, and Lemaire (1994) were able to experimentally induce subject–verb agreement errors by increasing their participants' memory load during a writing task, thereby documenting a causal rather than merely correlational link between ST-WM resource demands and writing outcomes.

If access to LT-WM resources depends on fluent task-specific encoding processes, as Kintsch (1998; Ericsson & Kintsch, 1995) argued, then one would predict that writers would be confined to ST-WM resources until encoding processes specific to writing, such as transcription and text generation, become sufficiently fluent. Only with fluent encoding processes can writers begin to build retrieval structures to information stored in LTM and, when such LTM knowledge is itself sufficiently rich, capitalize on the resources of LT-WM.

SKILLED WRITERS AND LT-WM

Is there evidence to support the claim that skilled writers use LT-WM resources, as Kintsch (1998) argued skilled readers do? To date, no writing research has explicitly used the LT-WM framework, but much of the writing research involving working memory and writing-relevant knowledge is consistent with predictions derived from such a framework.

In seminal work, Kellogg (1987, see also 1996) investigated general issues of working memory demands in writing. He was most interested in comparing the processing demands of the various subprocesses of writing, and he trained college students to distinguish their planning, translating, and reviewing processes. He then asked students to write essays, periodically probing them as to the process in which they were currently engaged. Although Kellogg found that translating (i.e., language encoding processes) sometimes demanded fewer resources than planning and reviewing, he concluded that none of the processes pushed writers near capacity limits. According to an LT-WM account, the college writers that Kellogg studied were readily able to encode representations of their developing texts into LTM and use the expanded resources of LT-WM. Such text representations in LTM probably also helped Kellogg's writers move between the probe and writing tasks, much as Kintsch (1998) suggested readers used LT-WM when interrupted during comprehension.

Levy and Ransdell (1995) also examined resource demands in skilled writers and argued that resource demands do not necessarily decrease for skilled writers, as may be expected if ST-WM resources were the only working memory resources involved in writing (see also Glynn, Britton, Muth, & Dugan, 1982). The fluency of language encoding processes of skilled writers should, according to traditional working memory accounts, reduce the overall processing demands in ST-WM. In their study, however, Levy and Ransdell (1995) focused not only on encoding processes but on the overall combination of knowledge and processing that skilled writers bring to the writing task. We may speculate that their skilled writers employed LT-WM as well as ST-WM resources. As their writers coordinated rhetorical forms, organized topic knowledge, and so on, they set for themselves a more demanding writing task and may well have devoted as much overall effort to composing as less-skilled writers. The key difference may be that the fluency of skilled writers' encoding processes and the accessibility of their writing-relevant knowledge shifted the locus of processing from ST-WM to LT-WM, resulting in better writing, if not lower resource demands overall.

Ransdell and Levy (1996) introduced the variable of individual differences (in reading skill) into their working memory task as they manipulated storage and processing demands. Ransdell and Levy asked participants to hold words in memory (the storage demand) while writing a sentence for each word (the simultaneous processing demand). In addition, Ransdell and Levy stressed word recall in one condition, thereby privileging storage, and stressed sentence complexity in another condition, thereby privileging processing. They found that the most skilled readers in the study could indeed allocate resources according to task demands, recalling more words when memory was stressed and generating more complex sentences when processing was stressed; but readers of lower skill were less flexible. An LT-WM interpretation of such individual differences would hold that the more efficient language processes and richer linguistic knowledge of the skilled readers enabled them to generate more complex sentences and better utilize LT-WM to meet the memory demands of the task.

THE ROLE OF KNOWLEDGE IN LT-WM

Thus, there is abundant evidence that general processes of language encoding (specifically, transcription and text generation) become more fluent with age and with the reading and writing experiences that generally come with age. However, according to Kintsch (1998), LT-WM depends on both efficient encoding processes and rich task-specific knowledge. Is there comparable research documenting relations between LTM knowledge and the development of writing skill? I focus here on two types of knowledge that have been the focus of considerable research: genre and topic knowledge.

Genre Knowledge

Familiarity with a genre can theoretically influence writing by providing access to an organized schema in LTM, and when writers can employ the resources of LT-WM, they are able to use such knowledge to assist ongoing processing. The protocol of one expert writer, a wine columnist for a large metropolitan newspaper (McCutchen, 1984), clearly revealed his genre knowledge in his detailed vision for the structural features of his column:

> The general structure has got to be, we've got to give them some information about Chateau Latour, make it kind of real to them, give them something to chew on, and then we've got to go through the tasting notes because we had a tasting of Chateau Latour from 1924 to 1967, which means that you have to save enough space to write about, you know, the wines themselves. But [first] we've got to say something about Chateau Latour. (p. 228)

Issues of genre also extend into writers' broader knowledge of the disciplinary community for whom (or perhaps more appropriately *with* whom) they write. For example, writers generally learn the discourse forms and honor the rhetorical values of their respective academic disciplines

(MacDonald, 1992; Myers, 1985; Stockton, 1995). Skilled writers seem to have ready access to, if not explicit awareness of, such rhetorical knowledge (Langer, 1992; Stockton, 1995).This ready access is evidenced by the fact that genre and stylistic knowledge seem to influence many other processes, including even lexical and syntactic choices (Barton, 1995; Bazerman, 1984; MacDonald, 1992; Vande Kopple, 1998).

In a recent study, McCutchen, Francis, and Kerr (1997) observed marked differences in access to genre knowledge by students with different levels of writing skill. We recorded protocols as middle-school students collaboratively revised texts in which we had planted both spelling and meaning errors. Skilled writers quickly developed a macrostructure of the text (Kintsch, 1998; Kintsch & van Dijk, 1978), reflecting their knowledge of the essay genre. Even during their initial reading, skilled writers recognized concluding statements that appeared in the introductions, noting these errors with comments such as "That shouldn't be there either 'cause it's too fast."

In contrast, less-skilled writers paid little attention to discourse-level features. They examined sentences individually and rarely considered the global structure of the text. Such a strategy made it particularly difficult for them to detect errors involving meaning (as opposed to spelling). The following excerpt is illustrative of the sentence-by-sentence strategy. Italics are added to highlight the student's evaluative statements.

> (reading)"Christopher Columbus was determined to find an all water route to the East Indies … East Indies." *That's good*. (reading) "Discovering this could bring him fame and fortune. However, however, Columbus also believed that the world was round." *OK*. (reading) "Many people"—*geez*! (corrects spelling, then reads) "laughed at this idea. They thought the world was flat." *Next, that's good*. (reading) "But still the sailors threatened to take over and turn, take over and turn back." *That's good*. (p. 673)

Thus, skilled writers seem to access a macrostructure for the text on which they are working, and such macrostructures are derived from their general knowledge of text structures, or genres. Extensive knowledge of a genre enables skilled writers to take advantage of LT-WM by building retrieval structures from the relatively small number of activated text elements in ST-WM to a more extensive, elaborated text representation stored in LTM. In our study, skilled writers therefore recognized when a text sentence was out of place (e.g., when an opening sentence, processed within ST-WM, links to the *Conclusion* slot of the essay schema in LTM). Lacking extensive genre knowledge[2] to enable LT-WM, less-skilled writers were constrained by the limits of ST-WM and forced to attend to one sentence at a time.

Existing research provides considerable evidence for developmental differences in genre knowledge and for links between genre knowledge and writing skill, even for children. Due largely to children's broad early experience with narratives at home and at school (Durkin, 1978–1979; Sulzby & Teale, 1987), very young children show signs of emergent narrative schemas (Brown, 1976; Stein & Glenn, 1979; Sulzby, 1985). Fitzgerald and Teasley (1986) provided evidence for a causal link between genre knowledge and writing skill, demonstrating that the quality of children's written stories improved after instruction in narrative structure. Children's knowledge of expository genres generally develops later (Englert, Stewart, & Hiebert, 1988; Langer, 1986), and comparisons reveal that children's written narratives are generally superior to their expositions (e.g., Cox, Shanahan, & Tinzmann, 1991; Hidi & Hildyard, 1983; but see Langer, 1986, as well as McCutchen, 1987, for qualifications). The difference in genre familiarity is apparent to children themselves, and they claim to be better at writing narratives than essays (Bereiter & Scardamalia, 1987). Even children with writing disabilities, for whom transcription processes exert considerable processing demands, produced spoken and written narratives that were similar in quality (Montague, Graves, & Leavell, 1991), whereas with essays, the written texts of children with writing disabilities were both shorter and lower in quality than spoken texts (Graham, 1990).

According to an LT-WM interpretation, access to rich knowledge of a particular genre enables writers to utilize the resources of LT-WM, building retrieval structures between text elements currently processed in ST-WM and organized text representations within LTM. However, children's writing may also benefit from genre knowledge even before their encoding processes are sufficiently fluent to support LT-WM. Children's use of genre knowledge may be more implicit, still operating within the constraints of ST-WM. According to Bereiter and Scardamalia (1987), the knowledge-telling strategy uses cues from the assignment (genre and topic cues) to formulate memory probes. When children are more familiar with a genre, the memory probes generated as part of the knowledge-telling process will be more systematically related and should result in retrieval of more coherent content. Thus, even though children may not have access to LT-WM, as expert writers do, children's genre knowledge may influence their writing because it is incorporated within knowledge-telling operations in ST-WM. We may predict, however, that retrieval times initiated by knowledge telling may differ from the 400 ms retrieval times associated with LT-WM processes, but such studies remain to be done.

[2]I am not suggesting that less-skilled writers have no knowledge of genre. Kintsch (1998) argued, however, that knowledge must be extensive, stable, and well practiced before it can be used to support the operation of LT-WM.

Topic Knowledge

Considerable research documents a substantial role for topic knowledge in a range of tasks, including reading and writing. Topic expertise has marked effects on readers' approaches to texts (Peskin, 1998; Spilich, Vesonder, Chiesi, & Voss, 1979; Voss, Vesonder, & Spilich, 1980; Wineburg, 1991). Even for young children, extensive topic knowledge increases the sophistication of cognitive processing in a variety of reasoning tasks (e.g., Chi, 1976; Means & Voss, 1985).

Instructional researchers have long argued that topic knowledge should improve writing (Calkins, 1986), and writing research supports that claim. Bereiter and Scardamalia (1987) observed that children generated more content during planning about familiar topics, compared with unfamiliar topics.[3] In a study of students from fourth, sixth, and eighth grades, I found that writers who were more knowledgeable about their topic wrote better texts than did writers who were less knowledgeable (McCutchen, 1986; see also Langer, 1984). Football texts written by football experts were both more coherent and more deeply elaborated than those written by nonexperts. In a subsequent analysis of data collected as the children planned, I also found that football experts produced longer plans than nonexperts.

DeGroff (1987) linked topic knowledge (of baseball) to the quality of children's first drafts, as well as to their revision. Topic knowledge was especially important in children's ability to specify the nature of text problems during conferencing. In addition, Butterfield, Hacker, and Plumb (1994) extended such findings to adult writers, documenting a positive relation between adults' topic knowledge (cricket and meteorology) and their revising effectiveness.

I also examined the effects of topic knowledge in the revision study discussed previously (McCutchen et al., 1997). Participants revised two texts, one about Christopher Columbus (a familiar topic) and another about Margaret Mead (an unfamiliar topic). In that study, both adults and middle-school students were more likely to detect and correct meaning-related problems in the Columbus text than in the Mead text. Topic knowledge, however, did not influence the correction of spelling errors.

An LT-WM analysis can elegantly account for such findings. Evaluation of the spellings of individual words required processing that was well within the constraints of ST-WM for these writers. Writers either noticed misspelling and automatically retrieved the correct alternatives, or they did not notice misspellings; but in both cases, knowledge of the text topic was irrelevant. However, to detect logical inconsistencies in meaning that spanned multiple sentences, writers needed to draw on the resources of LT-WM. Writers were better able to build effective retrieval structures to other relevant knowledge in LTM when the texts described a familiar topic (the voyage of Columbus). Thus, when revising the familiar text, writers had ready access (within 400 ms) to extensive topic knowledge that helped them detect and correct logical problems in text meaning. Lacking such extensive knowledge about Margaret Mead's work in Samoa, writers were less able to use LT-WM resources to relate elements across multiple sentences and paragraphs.

A further example of a skilled writer's use of topic knowledge can be found in a later excerpt from the protocol of the wine columnist (McCutchen, 1994). Early in his protocol he described his newspaper audience, an audience not necessarily expert about wines. Later, in the midst of a detailed description of the cabernet sauvignon grape, he interrupted his writing and said, "Now I should say 'esters and aldehydes,' but if I did that, then I'd have to explain about esters and aldehydes … Why not just talk about smells and flavors?" (p. 5). His deft change of focus (from the chemical basis of wine to its perceptual qualities) revealed that, even at the point of word choice, he was readily able to access related information in LTM to communicate better with his audience.

Like genre knowledge, topic knowledge may also benefit young writers even before they have access to LT-WM resources. During knowledge telling, topic cues are theoretically used to generate memory probes, in much the same way as genre cues are used (Bereiter & Scardamalia, 1987). Thus, writers who use the knowledge-telling strategy should also produce better texts when they are more familiar with a topic, not because they have access to LT-WM, but simply because the knowledge accessed by ST-WM probes is more interconnected. Even knowledge telling can thereby produce relatively coherent texts when its associative search processes operate on a rich and well-structured knowledge base. Again, however, we may predict differences in retrieval times associated with knowledge-telling versus LT-WM processes.

Berninger, Fuller, and Whitaker (1996) documented a clear link between knowledge and writing strategy in a study of graduate students working in a novel domain. Berninger et al. collected protocols as trainees in a school psychology program wrote case reports, and they saw these relatively skilled writers resort to a linear writing process much like knowledge telling. As the trainees struggled to coordinate newly acquired knowledge with a novel genre, many relied on the writing assignment to prompt step-by-step retrieval of relevant content, rather than on a global diagnosis fine-tuned to the specifics of each case.[4]

[3] Bereiter and Scardamalia (1987) found no quality differences, however, between the texts children wrote on familiar and unfamiliar topics. They asked children to suggest their own topics and thereby perhaps limited the extent to which the unfamiliar topics were truly unfamiliar. When familiarity has been assessed independently, rather than by the children themselves, differences in text quality consistently emerge (DeGroff, 1987; Langer, 1984; McCutchen, 1986).

[4] Kintsch (1998) described studies of text recall in which medical interns showed similar reliance on a more surface-level textbase, in contrast to experienced doctors who employed knowledge-dependent situation models.

Thus, without the benefit of deep topic knowledge and a familiar genre, skilled writers can lose access to LT-WM resources and resort to less mature strategies to cope with writing demands.

Of course, knowledge of topic and genre are not the only sources of knowledge that distinguish skilled from novice writers. Unlike the acute sense of audience that guided the wine columnist's word choice, attention to readers' needs are frequently lacking in the texts of less-skilled writers. Although children have been observed to make allowances for an absent listener (Littleton, 1998) and modify their arguments for different audiences (Cameron, Hunt, & Linton, 1996), their texts are not always reader-friendly and often contain ambiguous references and other textual infelicities (Bartlett, 1982; Beal, 1996). Flower (1979) described similar problems in the writing of older novice writers. In addition, students with writing disabilities (as well as young children) seem to lack the metacognitive, self-regulatory processes possessed by skilled writers (Beal, 1996; Englert, Raphael, Anderson, Gregg, & Anthony, 1989; Graham & Harris, 2000). Considerable research remains to be done to examine the implications of such knowledge for a theory of LT-WM in writing.

THE WORKING MEMORY PARADOX

Writing researchers interested in working memory, including myself (McCutchen, 1996; McCutchen et al., 1994), have often made the general claim that more fluent language generation processes free working memory resources and allow for higher level processes such as planning and reviewing. Details of the interactions of such processes within working memory have, however, remained sketchy. Such lack of specificity in our theories has led to something of a paradox in our attempts to wed traditional working memory theory and data: Less-skilled writers sometimes show more fluency generating text than do skilled writers.

Protocols of skilled writers (Flower & Hayes, 1980, 1981, 1984; Hayes & Flower, 1980; McCutchen, 1984, 1988) often reveal their hard work as they wrestle with ideas and language—the juggling act described by Flower and Hayes (1980)—whereas less sophisticated writers often jump straightaway into producing text with what looks like surprising ease. In fact, children are frequently incredulous when told that some writers think for 15 min or more before they write anything, and young writers often begin producing text within a minute of receiving an assignment (Bereiter & Scardamalia, 1987).

Contrast, for example, the protocol of the wine columnist as he began his weekly column (from McCutchen, 1994) with that of a second grader writing about her favorite activity (McCutchen, 1988). Before he wrote a word, the wine columnist laid out requirements for his opening sentence:

> Alright, so now you need a lead-in sentence and it's got to be something that's going to 1) catch the audience's eye, 2) given the way I usually write the column, it's got to be reasonably ornate, and 3) it's got to have something to do with the goddamn topic. (p. 4)

The protocol of the second grader, however, consisted largely of her saying aloud the words as she wrote them. She said aloud, "My dad can swim better than us all," as she wrote *My dad is the swimmer*. She said, "Sometimes my brother tries to dunk me" as she wrote *Sometimes my brother dunk's* [sic] *me*. She said, "My mom makes me swim back and forth ten times" as she wrote *My mother make's* [sic] *me swim back and forth over and over*. Her protocol revealed the knowledge-telling strategy in full swing, and somewhat paradoxically, her writing progressed more fluently than that of the wine columnist.

The solution to this apparent paradox is also evident in the protocol excerpts. The second grader did indeed generate text relatively easily within the constraints of ST-WM using her knowledge-telling strategy. Whereas text generation was the primary task the young writer set for herself, the wine columnist imposed task constraints reflecting his sense of genre, audience, style, and topic. That is, the wine columnist accessed a wide range of knowledge stored in LTM as he composed, and the constraints imposed by that knowledge complicated his writing task considerably. Still, such complications did not exceed his working memory capacity because he possessed two crucial components of writing expertise—fluent language encoding processes and extensive writing-relevant knowledge. The skilled writer was thereby able to transcend the limits of ST-WM and capitalize on the resources of LT-WM. The result was not necessarily an effortless writing process, but an effective one that yielded high-quality text.

CONCLUSIONS

I have used this review to explore implications of a theory of LT-WM (Ericsson & Kintsch, 1995; Kintsch, 1998) within the development of writing expertise. According to such theory, emerging fluency in language encoding processes enables developing writers to begin to manage constraints imposed by ST-WM; but without considerable processing fluency and extensive writing-relevant knowledge, novice writers remain limited by ST-WM capacity. Within such constraints, writing strategies such as knowledge telling may serve an adaptive function. Because knowledge telling merges content retrieval with text generation and results in actual words on the page, it gets the job done in many writing situations, and it does so within the limits of ST-WM.

Once language encoding processes become sufficiently fluent and knowledge bases sufficiently rich, writers can transcend the processing limits of ST-WM and capitalize on

LT-WM. Like beginning writers, skilled writers use ST-WM resources to construct the sentences that comprise their texts. However, their fluent sentence-generation processes, combined with their rich knowledge bases, enable skilled writers to link developing sentences to extensive knowledge stored in LTM. Their sentence constructions (including word choice, syntax, and semantic intent) can therefore be influenced by earlier text choices (stored in an LTM text representation), by structural constraints for the chosen genre, by knowledge about a specific audience, and by knowledge about the general topic. However, access to and coordination of these multiple sources of LTM knowledge become possible only when processing shifts from ST-WM to LT-WM.

I have sketched how LT-WM may contribute to writing expertise in only the broadest of strokes. Much empirical research needs to be done to fill in details and to evaluate specific theoretical predictions. For example, can we use response-time methodologies to distinguish knowledge-telling processes from LT-WM processes? Can we develop experimental situations that deny skilled writers access to LT-WM resources and systematically induce less mature writing? With a better specified model of working memory in writing, one that distinguishes LT-WM from ST-WM, we may begin to answer such questions.

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