Cognitive Technologies for Writing

Roy D. Pea, D. Midian Kurland

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Chapter 7

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ROY D. PEA
New York University
Laboratory for Advanced Research
in Educational Technologies
and
D. MIDIAN KURLAND
Bank Street College Media Group

Ludwig Wittgenstein: It is only the attempt to write down your ideas that enables them to develop (Drury, 1982).

INTRODUCTION

Current technologies are useful for improving the productivity and appearance of writing. However, with several notable exceptions, they neither offer qualitative advances over previous tools in helping mature writers express or refine their thoughts, nor help novices develop better writing skills. We propose that writing tools contribute indirectly to writing development (e.g., by encouraging more writing) when they should provide direct support, in ways to be described.

At the same time, an exciting new cognitive-developmental perspective on

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writing tools has begun to emerge at the interface of theory and practice. This coalition stems from productive interactions among writing teachers, computer scientists, cognitive and developmental psychologists, and practitioners and students of literary creativity.

Exciting as the growing use of computer writing tools in education and throughout society is, few technologies for writing closely connect *thinking* and *writing*. In reviewing this area, our aim is to spur thought and dialogue on this theme: How writing technologies could go beyond utility functions to "cognitive" functions. "Cognitive writing technologies" help a writer to *develop* the cognitive activities that are integral to writing processes. They would not just be "useful" for getting writing done faster or with fewer spelling or grammatical errors. They would be tools that can directly serve to develop more creative writing skills, be the writer adult or child, and involving effects of a different order of magnitude than the fine-tuning of meaning afforded by an on-line thesaurus, or contemporary software that catches a writer's lapses in noun-verb number agreement.

Historical Importance of Writing as Externalized Thinking

Rich accounts have been offered of how the birth and development of writing systems throughout the world dramatically changed the content and processes of thinking and education. This move from orality to literacy wrought fundamental changes in the *objectification of language* (Goody, 1977; Ong, 1982). The creation of language as a permanent (written) rather than effervescent (spoken) physical form meant that it could be carefully analyzed and critiqued. Speaker meaning had to lie more explicitly within the text for it to be understood (Olson, 1977).

These newfound possibilities had profound cognitive consequences. Our weak information-processing capabilities became supported—in what could be described as a cognitive revolution—by the *externalization* of thought as written language. There has been a venerable history of treating learning to write as closely connected to learning to think, both in history and in the individual (e.g., Bruner et al., 1966; Bruner & Olson, 1977–1978; Elbow 1983; Greenfield, 1972; Murray, 1980), and we are at the dawn of a new age of cognitive technologies for writing.

With existing technologies, radically new cognitive writing systems can be developed that could significantly transform not only the future development of thinking, but the processes and content of education. The required hardware and software tools are available, prototype programs offer proof-of-concept demonstrations of some important cognitive support functions for writers, and, as we hope to illustrate, many thinking-for-writing functions could be directly facilitated by tools but are not. Most of the remaining barriers to creating such writing environments are conceptual and design problems rather than technological barriers.

Consider the writing environment, the writer's long-term memory, and the "task environment." The interrelationships between task environment and writer memory are very intricate, since so much remembering consists of being *reminded* (e.g., Schank, 1982). We can imagine flexible systems that would allow writers of any skill level, while creating, evaluating, and revising text structures, to tap external stores of knowledge that would radically extend memory—that would, in effect, break down the barriers between mind and machine and facilitate the ready flow of knowledge in the service of writing in an integrated human-computer writing system.

For example, existing computer-based text-production tools, coupled to random-access videodiscs and other mass storage technologies, have remarkable potential for knowledge storing and structuring for writer use. Much attention is being devoted to the new storage technology of compact-disk read-only memory (CD-ROM), optical encoding of vast archival information (400–1000 megabytes per disk) on small, inexpensive, virtually indestructible disks (Shuford, 1985; Sprague, 1985). One can envisage making available the several million words in English, with their precision and expressive powers. Similarly, millions of images or symbols in nonlinguistic media could be accessed to help trigger the writer's memory and imagination. Existing query languages would allow users to use familiar English expressions rather than arcane Boolean operators to seek out information in these vast databases. CD-ROM would allow the first microcomputer internal access to huge relational databases of reference resources and works that could be accessed inside writing tools during the writing process. Such rapid search of stored images and text for specific content would be qualitatively distinct from writers' work with printed text archives.

What would the access interface between these resources and the writer's creative processes need to be like? What kinds of system queries could writers pose to find the path to the meanings they seek to express? How could the system help writers realize and achieve their rhetorical goals? How would different skill levels in writing, and different knowledge of the language and its nuances, influence writers' search processes? Finally, how could an author's text construction and its organizational methods be linked to these materials in ways that guide, not interfere, with the writing process? Before addressing such questions, we need to describe current writing tools, and how writing skills develop.

Goals for Writing Development

We subscribe to a number of tenets about basic purposes of writing that inform our approach. These tenets are central to many writing activities: (1) to write is to think and reflect; (2) writing can help communication with others; (3) writing may make one a better reader; and (4) writing can give writers a better sense of their own voice. Beyond this, we may roughly distinguish writing as art and writing as communication, comparable to Roland Barthes' (1982) "authors" and "writers". While most writing as art is also communicative, not all communicative writing is artful. This is critical for thinking about the goals and tools of writing development because not all people have the interest in or knack for writing as art. And little of the functional, communicative writing people do in business and everyday affairs is appropriately evaluated by aesthetic standards. Unfortunately, few people today are good at writing in either sense.

Yet writing as communication—to persuade, inform, instruct—is a necessary skill in our society. For example, many people are frustrated by their inability to write persuasive or expressive documents. Some find it difficult to find structure in and remember the gist of texts when reading—a skill that could be aided by writing experience.

Few people would know where to begin or what to do if they wanted to become good writers. The craft of writing is surrounded by a fortress of myths, which today's computer-based writing tools leave intact. Handing the novice a word processor is not enough. Such tools are opaque to the components of the writing process that studies of the psychology of writing have revealed. Most current computer writing tools are designed for skilled writers; they are more like production tools for *being* a writer than for *becoming* one. This distinction is not a sharp one because current technologies do *indirectly* contribute to a person's becoming a skilled writer, for example, by making it easier to write more, and reread and revise more readily. But good cognitive writing technologies would not only be useful for text production, they would *directly* facilitate the development of the writer's skills. Once chosen, such cognitive tools should provide *developmental writing environments* for continual "becoming." Our subsequent analyses illustrate the many ways in which writing tools could serve these direct supportive functions.

In sum, we believe most people can become good, clear writers as communicators, better understanding and conveying what they think by means of writing. New cognitive writing systems could help develop and perfect their skills. Before exploring aspects of the developmental psychology of writing that underpin these possibilities, we must establish the current context.

HISTORICAL BACKGROUND OF COMPUTER WRITING TOOLS

Writing by definition relies on some pairing of trace-forming and recording technologies—stylus and clay tablet, quill and papyrus, chalk and slateboard, pen and paper, keyboard and screen/disk/printer. While scribes and secretaries have always been available to a limited number of writers, major changes in writing technologies have recently provided material assistance to a much greater number of writers. More importantly, these capabilities are available to young writers. We now find word processors in the kindergarten and preschool.

The move toward computer-based writing tools and computer-based writing instruction has proceeded through three primary phases: typewriters, mainframe tools, and microcomputer tools.

Phase 1: Typewriter Technologies

The phase before computers defined the basic themes for much of what we find today. In 1868, Christopher Sholes created a typewriter that could register text as fast as a pen but unfortunately left us with the QWERTY keyboard, which was designed to keep key levers from jamming, not for its ergonomic efficiency. By the latter part of the 19th century the typewriter had become sufficiently reliable to be considered a viable writing tool, not just a production device—like the printing press—for producing neat-looking copy. The first important use of typewriters to help teach writing occurred in the 1920s. For the first time, students as young as kindergartners were able to write at a keyboard and observe the results of their efforts on neatly typed paper.

In one of the largest studies of the effects of word processing on children's writing, Wood and Freeman (1932) studied 2,383 students over 2 years as they learned to write on portable typewriters. Wood and Freeman observed that when compared with a control group who wrote without typewriters, the typers wrote more and with more expression, advanced in reading scores, became better spellers, and expressed greater interest in and enjoyment of writing. Despite these strong positive results and the wide acceptance of the typewriter as the basic tool of the professional writer, the use of typewriters in elementary school classrooms never caught on. Nonetheless, this study provided the first inkling that superior keyboard-based writing technologies could have an impact on early writing.

Phase 2: Mainframe Writing Tools

The second phase towards computer-based writing environments was the realization in the 1950s and 1960s that, in addition to manipulating numbers, the computer could be used to create texts. General-purpose program editors running on mainframe computers were suddenly used for entering text, not only data or programming code. Although clumsy by today's standards, these early editors and their descendants (e.g., ED, TECO, EMACS, ICE) demonstrated that one could quickly merge and modify texts using basic editing commands. When these editors were coupled with formatting and printing programs (e.g., FORMAT, RUNOFF), a better writing system than the typewriter was created. It was easier to alter a document without having to reenter the unrevised document parts. Thus, multiple revisions and multiple copies could be produced rapidly. However, these mainframe systems were expensive to operate, difficult to learn, and restricted to the few writers with technical backgrounds in universities and large businesses.

Phase 3: A Menagerie of Microcomputer Writing Tools

The third phase began with the development of less expensive minicomputers in the early 1970s. The development of the microprocessor later in that decade made possible the creation of personal computers, allowing word-processing capabilities to migrate from mainframes down to the small, affordable machines now in schools. Until quite recently, these developments focused on text production as electronic typewriting. We subsequently describe new trends that indicate the birth of a fourth phase: integrated writing systems that directly support the writer's thinking during the component processes of text creation.

First Steps

Lexitron introduced the first video display word processor in 1971, and in 1973, Vydec released their own video word processor with floppy diskettes for storage. At the same time, dedicated word-processing programs designed specifically for text production, formatting, and printing were developed to replace the older, general-purpose program editors/formatters running on the mainframes. Thus, it became possible to create a complete desktop writing and printing environment on a small specialized computer.

In 1974 the first of the true personal computers made its appearance when Microelectronics Instrumentations and Telemetry Systems (MITS) created the Altair. This $400 computer was primitive by current standards, but it began a dramatic drop in the cost of computer hardware and created a demand for useful software. Soon the first commercial microcomputer word processor made its appearance, Michael Shrayer's *Electric Pencil*.

An Explosion of Word Processors

The demand from early computer owners for better word processors soon led Seymour Rubinstein, founder of MicroPro, to commission Rob Barnaby to write a word processor for his company. That program—*WordStar*—was released in mid-1979 and became an immediate hit. Over the next 6 years several million copies of *WordStar* in its various forms were sold, and undoubtedly an equal or greater number of illegal copies were also made. Personal computer-based writing had arrived.

Today, there are literally hundreds of word-processing programs available to run on practically all existing computers (e.g., *WordPerfect, MultiMate, AppleWriter:* see August 1985 *Byte* and January 28, 1985, *PC Magazine* for a current sampling). In addition, there are computers with special keyboards and integrated high-quality printers that are dedicated to text production (e.g., *IBM. Displaywriter, Wangwriter*). Complete text production systems (computer, keyboard, mass storage device, display monitor, printer, and word-processing software) can now be assembled for less than a thousand dollars,

although most acceptable systems still cost several times that amount. Such systems permit the writer to enter text as if at a typewriter. But they also allow the writer to quickly delete, move, or copy letters, words, and larger text blocks within the document; insert new text without having to retype or rearrange the surrounding text; find and replace specific words or phrases; change headings, margins, fonts, and line spacing at will; have page numbers and running heads or footers automatically inserted; and part or all of the document printed out as many times and in as many ways as the writer desires.

From 1983 to 1985, as word-processing software dropped in cost, there was an astronomical growth in computers in schools in the United States—school computers now number in the millions. Students do some of their writing with word processors, and businessmen write on portable computers on the road.

Enhancing Word Processing

The most recent developments in the third phase have been new programs designed to work with a word processor. They have primarily been directed at enhancing the text-production process. We shall review five major categories of enhancers: (1) text-analysis programs, (2) on-line writing supports such as thesauruses and spelling checkers, (3) prewriting and text-planning programs, (4) integrated report-writing software, and (5) laser technology page-printer and page-layout software systems. In describing these developments, we will not restrict ourselves to programs for micros because many prototypes worked out initially on mainframes are now being ported down to micros.

Text analysis programs. One of the first and most complete writer-support systems was The *UNIX WRITER'S WORKBENCH™* (Frase, 1983; Macdonald, 1983), a set of related programs developed at Bell Laboratories to augment text processing on the UNIX system. The *UNIX WRITER'S WORKBENCH* and the many programs for microcomputers derived from it (e.g., *The Word Plus, Grammatik*) take a text that has been produced with a word processor and evaluate it according to a set of algorithms designed to identify potential problems. For example, these programs check a document for misspellings and, on request, can suggest possible correct spellings for any word the program does not find in its dictionary. Other programs can check a document for unbalanced quotation marks or parentheses, misplaced or missing capital letters, excessively long sentences, sexist language, jargon, overuse of the passive voice, and many other grammatical solecisms and stylistic infelicities. They can also provide statistics on average sentence length, average number of syllables per word, number of technical words, and readability level according to various scoring methods. With this information, the programs can reference stored exemplars of different types of text, compare the writer's text to these norms, and provide feedback about how closely the writer's text conforms to established norms for a particular kind of writing. Thus, a writer could find out that the sentences in an essay were on average seven words longer than the standard for a good essay, and that 23% more four-syllable words than the norm were used, which might make the text hard to read.

On-line writing supports. In addition to programs that provide feedback after a text has been produced, there are programs that work in tandem with the word processor on-line while the writer is writing. For example, there are electronic thesauruses (e.g., *The Random House Electronic Thesaurus, Turbo Lightning, Word Finder, Word Proof II*) that permit the writer in the midst of composing to call up on the screen a thesaurus entry for a selected word, and have one of the alternate words in the entry inserted automatically into the text.

Prewriting and text-planning programs. A third class of support programs that have emerged assist such prewriting activities as idea generation, idea organization, and planning of text structure (Bruce, Collins, Rubin, & Gentner, 1982). These programs are often called "idea processors" (Bruce, 1985; Owens, 1984). It is possible but awkward to use word processors effectively for creating outlines, for rapidly jotting down ideas, or for organizing these ideas before shaping the final text. Specialized programs now provide support for these writing techniques. Some of the better-known tools are outlining programs (e.g., *ThinkTank, Fact Cruncher, Freestyle, MaxThink, Framework*) and idea prompters that help authors plan a text (e.g., QUILL's *Planner*), or manage text annotations (ANNOLAND: Brown, 1985). Xerox's *Notecards* provides an authoring environment for collecting and linking information on notecards, notecard browsing and structuring tools, and sophisticated word-processing capabilities (Brown, 1985; Collins & Brown, 1986). For the young student, there are programs that provide ready-made content, but allow the writer to experiment with alternative structures or organizations (e.g., *Storymaker:* Rubin, 1980).

Integrated report-writing environments. A fourth class of programs represents the advent of integrated software environments that combine database management systems, word processors, spelling checkers, spreadsheets, telecommunication links, and business graphics applications. Prominent examples include *Framework II, Symphony, Ability, Enable,* and *AppleWorks*. These programs allow the easy integration of data tables, charts, and graphs with text created with a word processor.

Desktop publishing. A fifth class of technologies that are beginning to change writing are the extremely rapid laser-based page printers coupled with layout programs, most prevalent today for the Apple MacIntosh computer (e.g., *ReadySetGo, Page Maker, MacPublisher*). These technologies have been heralded as creating a desktop publishing industry, and for only a few thousand dollars beyond the cost of one's computer and software, one can now create documents with the appearance of expensive books, newspapers, and magazines. Simpler versions of page-formatting software for school computers, such as Broderbund's popular *Printshop* and Springboard's *Newsroom* allow sophisticated classroom publishing.

Summary of Phase 3 and New Directions

The recent expansion of text production tools into these five new areas has gone a long way toward improving the technical capabilities of the writing environment. However, even the most sophisticated of these computer-based tools still represent slave technologies. Available writing tools have taken the place of typing support and, to a lesser extent, the copy editor, but they cannot serve as a constructive critic, writing process expert and teacher, responsive audience, or collaborator. The next phase in the evolution of writing technologies must begin to address these fundamental problems.

Whereas Phase 3 developments such as the text-planning and prewriting tools described offered the first "proof of concept" demonstrations of the usefulness of direct supports for the writer's thinking processes during writing, Phase 4 work will continue to define new direct supports for the writer's thinking while writing. The fourth phase, as will be described, is likely to consist of wide-ranging prototype development to explore the possibilities of using computer technologies to directly support different facets of the author's thinking during the writing process.

Major computer-based writing technologies that are under development or in the planning stages are proceeding along two complementary courses: to make the feedback available to writers more "intelligent," and to make more flexible, "personalizable" writing tools that could help bridge the gap between thinking and writing.

Developers are incorporating recent advances in artificial intelligence and natural-language understanding to make writing programs that can provide more detailed and content-specific forms of feedback. Existing systems deal with well-formedness and some aspects of style and genre. IBM's *Epistle* text-critiquing system (Heidorn, Jensen, Miller, Byrd, & Chodorow, 1982), now in prototype form, attempts to combine a word processor with a powerful natural-language parser and an extensive dictionary and database of information about business correspondence and other document types. The parser is used to determine the syntactic structures of sentences (Heidorn et al., 1982). *Epistle's* capabilities include all of those offered by the *UNIX WRITER'S WORKBENCH*, created at Bell Labs (Frase, 1983; Macdonald, 1983), but the latter system does not have a syntactic parser (Lance Miller, personal communication, November 1985). The stylistic analyses available from *Epistle* are intended to go beyond those of the *UNIX WRITER'S WORKBENCH*.

Epistle is expected to have the capacity to evaluate any text by providing a critique of, among other problems, subject-verb disagreement, wrong pronoun case, noun-modifier disagreement, nonstandard verb forms, nonparallel structures, overuse of the passive voice, excessive use of negatives, excessive sentence length or clause complexity, poor readability scores, and whether the distance between subject and verb is too great. *Epistle* is said to enable the user to take a text and produce a synopsis of its contents, highlight important sections, and generate index terms based on conceptual or thematic characteristics. Its ability to do syntactic parsing also allows for stylistic critiquing. Current elaborations on *Epistle* involve partitioning of major document genre and subgenre branches according to major social institutions: e.g., Law, Medicine, Education, Military, the Press, Government, Commerce (Miller, 1985). Detailed planning templates and style-evaluative standards for each subgenre will assist the writer in creating and evaluating documents. Current document typologies permit critical comparisons between rhetorical structures called for by the subgenre and the structures present in the document; prompts concerning discrepancies are then presented to the writer (Miller, 1985).

While work on intelligent systems like *Epistle* is under way, writing technology is moving in a second direction: flexible modifiability by users (Frase, in press). Until now, even the most sophisticated word processors have been fairly inflexible. The order and manner in which they carried out their operations was set by the designer. In many cases the writer was forced to adopt a method of writing by how the program worked, not by his or her writing style. Writing systems are under development that can be flexibly modified by the individual writer, and eventually modify themselves automatically to complement the particular writing style or preferences of the writer (Brown, 1982, 1985).

Systems with greater flexibility already have emerged that offer some user control by permitting the writer to program function keys or create "macro" commands to perform a favored sequence of commands (such as boilerplate paragraphs or commonly used words) with a single keystroke or command (e.g., *ProKey, SuperKey, Keyworks, Microsoft Word, Framework II*). However, while such capabilities speed up editing and formatting within the existing system architecture, they do not allow writers to create personalized writing environments of their own choosing. Several word processors do go further in this direction by providing their own internal programming language by which a user may extensively customize the operation of the word processor (e.g., *Finalword, AppleWriter II*). However, a good understanding of programming techniques and the time and willingness to experiment are required to modify these programs.

We would like to see "developmental" word processors that come with a simple set of commands and functions that can, over time, be modified, extended, or redesigned to better support individual writers as they mature.

Writing technology has changed rapidly and in many directions during the past two decades, perhaps more than in the previous 200 years. However, the writing technologies developed thus far, no matter how superficially powerful, do not teach writing or explicitly help make a person a better writer. To understand the forms that cognitive writing technologies and related research should take in the future, we must consider what the novice or expert writer actually does with the available writing technologies.

COGNITIVE SCIENCE OF WRITING: A PRODUCTIVE FRAMEWORK FOR ASSESSING THE COGNITIVE ROLES FOR WRITING TECHNOLOGIES

Research on the cognitive processes of writing thus far indicates the *accessibility* of cognitive writing technologies, but there are few examples of software tools that actually build on this research. Cognitive process models and writing studies suggest many "developmental fronts" where new tools could support the mental activities involved in composing text.

Demystifying Writing

For years, writing has been regarded as a mysterious process that only those "good at writing" could do. The widely publicized quirks and idiosyncracies of well-known writers have contributed to this mystique (Green & Wason, 1982; Plimpton, 1981).

Recently, we have seen a progressive demystification of writing, published largely in technical reports. This important demystification process has been in large part due to extensive, careful investigations of the writing processes of novice and expert adult writers and the development of writing abilities in children, but also to rich observational accounts of the successful teaching of writing (e.g., Calkins, 1986; Elbow, 1981; Graves, 1975, 1983).

How has writing become less mysterious? A paradigm shift has occurred—from viewing writing as an unanalyzed holistic process to the widespread recognition that writing is a complex skill comprising distinguishable component activities such as planning, translating, reviewing, and monitoring. The tacit has been made explicit. Recent studies of different cognitive activities involved in writing seek to identify its basic component processes and how they are orchestrated or managed during the activities of writing (e.g., Bracewell, Frederiksen, & Frederiksen, 1982; Flower & Hayes, 1980a, 1980b, 1981a, 1981b; Hayes & Flower, 1980a, 1980b). Writing has been demystified to the extent that such accounts allow for systematic testing of alternative models of how text is composed, and how writing skills are developed through instruction and writing practices.

The promise of improving writing instruction through various intervention strategies based on these findings has also been assessed, particularly in research programs at the Ontario Institute for Studies in Education (e.g., Bereiter & Scardamalia, 1983a, 1983b, 1985; Scardamalia & Bereiter, 1983a, 1983b, 1985, in press). Since many excellent introductions to this work are available (e.g., Beaugrande, 1984; Scardamalia & Bereiter, 1985), our main purpose will be to cite findings and provide some terms the reader can use in thinking about the cognitive processes of writing with technologies.

Writing as Complex Problem Solving

Cognitive studies of writing begin with the observation that writing is a complex cognitive task in which many cognitive demands impinge on the writer at the same time. Writing is viewed as "a process of generating and editing text within a variety of constraints" such as structure, content, and goals (Collins & Gentner, 1980, p. 52). On the one hand (perhaps the left), the writer has ideas to communicate and experiences to embody in written text. The nonlinearity, rich imagery, and symbols of thought so glorified during the romantic period provide crucial but unrefined gist for the writer's tasks. On the other hand (perhaps the right), the writer is creating a text structure governed by many constraints and conventions.

Perhaps the most obvious conventions, and certainly the central emphasis of traditional writing instruction and current computer-assisted instructional writing programs, are those of spelling, word meaning, and grammar (Rubin, 1983). But larger units of analysis—closer to the ancient discipline of rhetoric pioneered by Aristotle (Cooper, 1932), reawakened and developed by Burke (1950), and today designated variously as either sociolinguistics or "pragmatics"—also impose constraints on the writing process.

One must, for example, think about the objectives of the written piece, the anticipated audience, whether the topics and comments are known or new to the reader, the structure of arguments, and the genre of the composition as a whole (e.g., legal brief, essay, sonnet, mystery, business letter). The author may focus on making the text enticing, comprehensible, memorable, or persuasive, and these pervasive goals of writing are realized through different structures and devices at different levels of the text (Collins & Gentner, 1980). Taken separately, each of these constraints may be manageable, but taken together they can constitute a serious impediment to human memory and cognitive processing. Like the centipede watching its own feet, a writer paying attention to all these directions may never set pen to paper (Flower & Hayes, 1980b).

Writing is viewed in these cognitive studies as a *complex problem-solving* activity (Bracewell, 1980; Hayes & Flower, 1980b) comprised of a small set of basic mental processes. Writing calls on the author to manage available mental resources to deal with the Janus faces of writing—the creative and the constraining.

This view of writing owes much to the general theory of problem solving developed by Newell and Simon (1972) and their colleagues (also see Greeno & Simon, in press; Simon, 1981). Since the 1960s, this perspective has been applied successfully to thinking and developmental processes in content areas from mathematics and science to chess, engineering, and medical diagnosis, and has recently had considerable influence on instructional psychology (e.g., Gagné & Dick, 1983; Glaser, 1982; Greeno & Simon, in press; Resnick, 1981, 1985).

A major difference between recent work on writing development and earlier cognitive science accounts of problem solving for other content areas is the broader sense given to the term "problem solving." Whereas earlier studies emphasized the solving of problems with well-defined goals, it is now recognized that goals can themselves be altered during work on a problem. Problem finding has thus come to be incorporated into the study of problem solving; writers often redefine the rhetorical problem their writing is "solving" by means of the writing activity itself (Murray, 1978). Bereiter (1980) has called this prized activity "epistemic" writing.

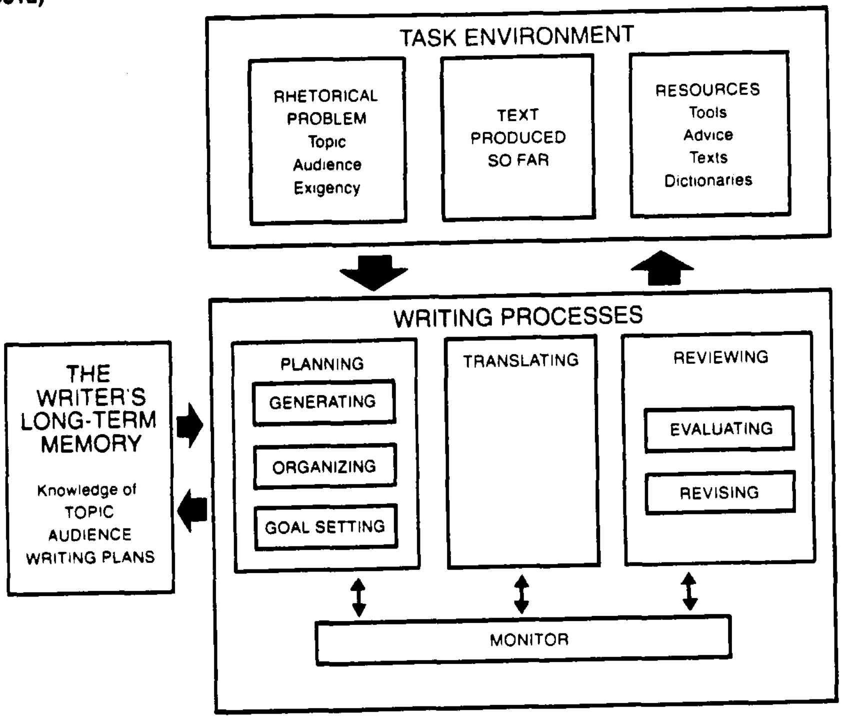
Flower and Hayes's Cognitive Process Model of Writing

The cognitive science perspective will help structure our discussions of writing development and roles for cognitive writing technologies. We will describe a cognitive process model of writing as problem solving, how data on writing activities relate to it, and the general framework of the model. We then explore how cognitive process models relate to the development of writing skills and, finally, cognitive writing technologies.

Although different investigators offer different cognitive models of writing, Flower & Hayes (1981a) present a lucid account of their cognitive process model that suits our purposes (Figure 1). Three major elements of the task of writing are distinguished: the *task environment* (including "everything outside the writer's skin": what the rhetorical problem is, the text as it evolves, writing tools, and sources of information to be used in writing); the *writer's long-term memory* (including knowledge of topic, audience, and writing strategies); and *writing processes* (including planning, translating, and reviewing—controlled by an executive monitor). The purpose of such a model is to help sharpen thinking about writing by describing the parts of the cognitive writing system and how they work together to create a written text.

A process model centers for analysis on units called basic mental "processes," such as generating ideas. We can call any execution of a basic mental process a mental "act." According to this model, any of the mental acts described may be carried out at any time during the writing activity, and one

Figure. 1. Cognitive processes of the writing model (adapted from Flower & Hayes, 1981a)



Note: As Flower and Hayes note, "the arrows indicate that *information* flows from one box or process to another; that is, knowledge about the writing assignment or knowledge from memory can be transferred or used in the planning process, and information from planning can flow back the other way. . . . The multiple arrows . . . are unfortunately only weak indications of the complex and active organization of thinking processes" (pp. 386–387)..

basic mental process "monitors" the use of the others. There is no strict linearity to these activities.

Data for cognitive studies of writing are provided by think-aloud protocols as a writer works (Bereiter & Scardamalia, 1983b; Hayes & Flower, 1980a). These protocols are transcribed records of a writer's spontaneous descriptions of what is going on in his or her mind while writing. They help reveal the kinds of mental processes that underlie text composition activities and how they are juggled during writing. The *kinds* of mental acts different writers engage in while writing have much in common, and the model attempts to capture these acts. However, the ways in which novices versus experts, or children versus adults, orchestrate these mental acts during writing varies tremendously. Some major findings from such studies will be cited below.

Before stating the basic mental processes that make up this cognitive model of writing, we must describe two elements of the writing environment depicted in Figure 1.

First, within the *task environment:*

1. There is a RHETORICAL PROBLEM to solve, for example: "Write a critical review of Bill's cheese soufflé for potential future diners." Writing is the task of solving that problem, given some definition of topic and audience.

2. There is an EVOLVING TEXT, which opens or closes off options for how it can proceed according to the vast array of linguistic and rhetorical conventions already mentioned. For example, a topic sentence serves to limit and refine a paragraph's possibilities.

3. There are RESOURCES and TOOLS for writing, such as: teachers; books, index cards, and other reference materials; writing materials; and computer-based writing tools. We have taken the liberty of adding this box to Figure 1 in order to acknowledge the important role of such prior externalizations of thought for creating new writing.

Second, within the *writer's long-term memory (LTM),* there is knowledge about topic, audience, writing plans, and types of writing problems. Unlike the active processing of short-term memory, LTM has a more stable organization, and the two major problems for the writer are to *access* the knowledge that will be useful for the writing under way, and to *organize* that knowledge to meet the needs of the rhetorical problem.

Now we move to brief descriptions of the basic mental processes of the cognitive process model of writing. Within the box called "writing processes" three major mental processes are shown: (1) PLANNING, (2) TRANSLATING, and (3) REVIEWING. A fourth, MONITORING, functions strategically to determine in what order processes are engaged in.

1. PLANNING is defined broadly as the act of building a representation (e.g., of images, propositions, feelings) of the knowledge to be used in writing, and involves three major subprocesses: (a) GETTING IDEAS, which includes accessing knowledge from long-term memory or collecting ideas from resources (that may not appear in the final text); (b) ORGANIZING, which helps to give meaningful structure to the ideas, and from which new ideas can emerge as a result of this browsing and combinatorial activity; and (c) GOAL-SETTING, which sharpens the definition of the rhetorical problem by generating and revising goals and subgoals for the text.

2. TRANSLATING is defined as the process of turning ideas into written language, and is subject to such constraints on linguistic form as spelling, syntax, and word choice, and to such pragmatic constraints as given/new topical organization or the temporal sequence of narration.

3. REVIEWING is the process of going back over the text or such writing processes as planning, and involves two major subprocesses: (a) EVALUATING, by which outcomes of writing processes (such as translating or planning) are judged against certain standards; and (b) REVISING, by which changes are made in the products of the mental processes of writing (e.g., text, goals, or ideas).

4. MONITORING is the complex "executive" process that oversees writing processes and allows the writer to decide when to move from one mental process to the next (e.g., when to stop translating and start reviewing).

Several important empirical findings come from using this model as a tool for observing the progress of writing activities: (1) writing processes are *hierarchically organized;* (2) the guidance of writing processes emerges from *goal-directedness;* and (3) the goals of writing are *epistemically reactive;* that is, they are continually regenerated through what is learned during the writing process.

1. These basic processes of writing are not executed in rigid sequence, but are *hierarchically organized* so that they may be flexibly embedded within other basic writing processes. This observation counters "stage models" of writing that view text composing as a linear process of distinct stages, such as Pre-Write, Write, and Re-write (Rohman, 1965), or the classical emphasis in writing instruction on the "necessity" of a topical outline structure before text production. Flower and Hayes (1981a) cite an example of a writer who, after attempting to TRANSLATE the first sentence of a paper, created a subgoal sequence of PLANNING, TRANSLATING, and REVIEWING to try out another first sentence as part of the larger attempt to TRANSLATE. These modular processes may be selected during writing processes as "tools" to help solve the writing problem.

2. *Goal-directedness* is what guides a writer to invoke specific mental processes during the act of composing, thus giving writing its purposefulness. A hierarchical network of goals is created (in fact, often discovered as ideas are generated, organized, and translated into text) which directs the sequencing of mental processes. Evolving goals thus etch out a path for the composing process.

3. Not only does writing help promote thinking, but *as we learn during writing, our writing goals often change* (Scardamalia, Bereiter, & Steinbach, 1984; Murray, 1978). While many goals for writing may be automatically accessed from memory, the creative setting of subgoals and the subsequent discovery or redefinition of writing goals during the composing process is a basic fact about mature writing.

Writing Development

Given this cognitive process model for writing, what is it that develops as writers improve? Do we know how to design an instructional psychology of writing? How could the cognitive writing technologies we are calling for support processes of writing development? These are the major questions, and research has only begun to address them. Our strategy is to highlight findings on writing development with significant implications for the kinds of cognitive writing tools needed to foster writing development. We will illustrate the main weaknesses or "stress points" in the cognitive system for writing in underdeveloped writers. Findings which demonstrate that the differences between good writers and novice writers lie in the mental processes they orchestrate and how they orchestrate them are of particular interest. These data give rise to two important questions concerning new writing technologies: How can the knowledge that experts appear to have be made available to novices? How can cognitive writing tools serve in this pedagogical enterprise?

Problems of Novice Writers

Some clarification of the terms "novice" and "expert" writers is essential. The term "novice writer" as used in the literature on the developmental psychology of writing refers to those who *do* write—whether in school, for business purposes, or for other functional activities in their lives—but whose writing is problematical. It does not refer to nonwriting individuals, be they illiterate or functionally illiterate (i.e., those who rarely use what writing skills they have).

The technical meaning of the term "expert writer" is more elusive, since it does not necessarily refer to professional writers, such as novelists or journalists, although such people often are expert. The popular definition of expert writers (i.e., those who write for a living) excludes a large group, such as academicians or business people, who write all the time and are considered "expert writers" in cognitive studies of writing. Perhaps the best working definition is that expert writers are those who are recognized as such by their peers in the genre(s) they have mastered.

The chief distinction between novice and expert writers is that the novice reaches the plateau of *writer-based prose* and may never progress to the *reader-based prose* of the expert (Flower, 1979). In writer-based prose, which gets most writers through school and many through business-related writing, the focus is on the text in isolation, produced in linear, nonreflective fashion (Larson, 1971), rather than on the text in relation to its intended audience (Maimon, 1979). Bereiter and Scardamalia (1983) call this overused procedure the "knowledge-telling strategy." Kroll (1978) describes this general problem of novice writing as one of "cognitive egocentrism." In Flower's (1979) words: "In its language and structure, Reader-Based prose reflects the *purpose* of the writer's thought; Writer-Based prose tends to reflect its *process*" (p. 20).

What Flower describes as writer-based prose would appear to be, in part, a literal translation of oral speech conventions into written language (Shaughnessy, 1977). Many other problems of novice writers emerge as symptoms of this "memory-dump," mainly linear, approach to writing. We believe that an explicit focus on these categories of difficulties has important consequences for the creation of future writing tools. The difficulties of the novice writer are presented in terms of the cognitive process model outlined earlier:

1. PLANNING (GENERATING IDEAS, ORGANIZING, GOAL-SETTING). Finding a focus and ideas in memory to write about is often hard for novices (Bereiter & Scardamalia, 1982; Caccamise, 1985). Once they do generate an array of *ideas* from long-term memory as text, they have major problems in organizing them. Their texts and text-production processes reveal little preplanning. Explicit writing goals are rarely set, and if set, are rarely revised (Perl, 1979; Sommers, 1980), in contrast to skilled writers (Flower & Hayes, 1981b). And, unlike the detailed planning episodes of expert writers thinking aloud while writing (Flower & Hayes, 1981b), the think-aloud protocols of school-age writers lack reflective statements on goals, anticipations of difficulties, conflicts between alternate schemes, and the like (Burtis, Bereiter, Scardamalia & Tetroe, 1983).

2. TRANSLATING. Novices create text in order of recall (Flower, 1979), paying little attention to pragmatic constraints such as whether information is known to or new to the reader, and overemphasize correcting any spelling, grammatical, or word choice errors during the text generation process (Nold, 1982).

3. REVIEWING (EVALUATING, REVISING). When reading text they have written for revision purposes, novices have difficulties finding the organizational parts of *text structure* (Scardamalia & Bereiter, 1983b). The novice writer's mental representation of the text is often limited to the text itself, unlike the skilled writer, who also thinks in terms of gist, goals, organizational structure, and content (Beaugrande, 1984; Cooper & Matsuhashi, 1983; Flower & Hayes, 1984). The novice cannot state the main point of the text or explain its rhetorical goals. Sentences are arranged in order of recall rather than in terms of their imagined effect on a reader. Novices rarely reorganize higher level text representations such as paragraphs, for example, to better correspond to a canonical text-level form such as an argument. They instead restrict their revisions to local mechanical corrections, and word/phrase substitutions and deletions rather than macrostructural changes (Butturff & Sommers, 1980; Faigley & Witte, 1981; Sommers, 1980). Scardamalia & Paris (in press) provide data that indicate that fourth to sixth graders need to learn to think in terms of the intermediate representations of gist and goals *before* they can construct abstractly planned whole-text structures such as the opinion essay form.

4. MONITORING. Writing novices are beset with two major classes of problems with monitoring. First, novices rarely use "executive" processes to *monitor writing* processes and manage the deployment of the different mental processes involved in writing in relation to their writing goals: PLANNING (GENERATING, ORGANIZING, GOAL SETTING), TRANSLATING, and REVIEWING (EVALUATING, REVISING). One serious repercussion of the lack of spontaneous executive activity is the novice writer's lack of recognition that writing is a *multistage* process that can be worked on in parts, rather than in parallel. However, Scardamalia & Bereiter (1985) describe the effectiveness of providing "procedural facilitation" interventions on the quality of texts produced by novice writers. Procedural facilitators are those nonsubstantive methods that help to organize the student's mental activities during writing by prompting the student to take specific types of action (e.g., cuing the student to state the text's purpose or main point). Secondly, novices have difficulty *self-monitoring* just what their writing problems are, and getting access to techniques and methods for overcoming and managing them.

Novice Writers: Children Versus Adults

Although research indicates a commonality of difficulties experienced by novice child and adult writers—particularly in relation to writer-based prose—there may also be differences. Maturational and experiential histories, for example, are quite distinctive for children and adults. And, if child novice writers have more obstacles to overcome than adults in developing writing skills, the design of developmental writing technologies should reflect these differences. We will describe below some probable ways in which child and adult novice writers are likely to diverge.

1. PLANNING (GENERATING IDEAS, ORGANIZING, GOAL-SETTING)

A. GENERATING IDEAS

Rhetorical problem and genre knowledge. Adults are apt to have read a broader range and more examples of text structures and genres than children. Adults are thus likely to know more about the rhetorical problems in a given genre. Skilled writers clearly do (Bereiter, 1980).

Topic knowledge and word knowledge. Adults know more about the world than children (Keil, 1979). The same is true of word knowledge (Miller & Johnson-Laird, 1976). On-line dictionaries, databases, encyclopedias, and thesauruses may alleviate but not erase these differences (Miller, 1979).

B. ORGANIZING

Differential LTM structure. We would expect the texts of adult novices to reveal more hierarchical structure than those of children (especially at the preoperational stage), because adults have more highly structured and networked long-term memory (LTM) than children.

C. GOAL-SETTING

Goal-setting and revision. Adult novices make references to goals in planning (Flower & Hayes, 1981b), whereas sixth-grade writing novices rarely do (Burtis et al., 1983). Child novices may also have a more restricted taxonomy of purposes than adult novices for the effect they would like to have on their readers. The development of metapragmatic knowledge or rhetorical skills may be a lengthy process, which adults achieve implicitly through their extensive experience in communicative contexts, social exchanges, and through reading. McCutchen and Perfetti (1982) show that between second and eighth grade, student writers attend to progressively more constraints in the writing assignments they receive.

Audience imagination. The development of social cognition (Damon, 1979) is apt to have important effects on the child's ability to imagine audience characteristics and purposes of the reader (e.g., reading for gist, for humor, for instructions).

Writing plans. The development of planning skills is not yet well-understood, but with age there are apt to be many developmental achievements in planning (Pea, 1982; Pea & Hawkins, in press) that will distinguish the planning-for-writing competencies of child and adult novice writers. School-aged writers have difficulties in planning text compositions (Burtis et al., 1983; Tetroe, Scardamalia, Bereiter, & Burtis, in press).

2. TRANSLATING

Fluency of translation. With much more extensive oral experience than children, adults' fluency in moving from thought to text is likely to be greater. For adult novice writers, the sheer automaticity of translation with regard to spelling, punctuation, and writing/typing skills is likely to allow them to write more text (Scardamalia & Bereiter, 1985). Simon (1973) found that many primary-school children when writing subvocalize each word and sometimes individual letters, although these mechanical concerns fade by the end of elementary school (Scardamalia, Bereiter, & Goelman, 1982).

3. REVIEWING (EVALUATING, REVISING)

A. EVALUATING

Knowledge of critical text standards. Evaluating is likely to be a major age-linked bottleneck to cognitive process writing instruction. Text self-evaluation depends on the availability in LTM of standards of evaluation that are likely to accrue with age. These include the canons of literary genre for good-formedness (aesthetics), the achievement of rhetorical effects (pragmatics), and various metalinguistic judgments about well-formedness (spelling, word choice, grammar, intersentential cohesion). Some standards can be stated as explicit algorithms for software analysis of texts. Writers can thus receive normative assessments of their texts from such systems as IBM's *Epistle*, or Bell Lab's *UNIX WRITER'S WORKBENCH*. But we know little about whether or not using such systems causes child or adult writers to internalize these standards for improving their future writing.

B. REVISING

Knowledge of revision methods. Revising techniques, employed to improve what evaluative assessments have found wanting, are numerous (Collins & Gentner, 1980; Elbow, 1981) and often cognitively complex, particularly at the whole-text (rather than the paragraph or sentence) level. Often the writer has available a variety of ways to make the text come closer to evaluative self-standards or those of critics. The cognitive operations that guide the expert writer's sequence of choices for locales and methods of revision are not well understood, but we suspect that they are too complex for use by elementary school children's limited mental processing capacities (Case, 1985).

4. MONITORING

Availability of executive processes. Considerable evidence reviewed by Scardamalia & Bereiter (1985) indicates that until the end of elementary school, child novice writers do not use executive control skills for switching between different subprocesses of writing, instead attempting to cope with all of them simultaneously. Only between sixth and eighth grade do novice writers' think-aloud protocols begin to reveal abstract planning processes (Burtis et al., 1983). Child novices are thus more likely than adults to have difficulties controlling the use of different writing processes.

Talk about executive processes. Discussing the monitoring of cognitive processes involved in writing (see Figure 1) is central to effective writing instruction. There are likely to be lower age limits to the effective use of discussion of abstract mental processes and states, although the writing of 6th graders apparently benefits from learning to use specific planning cues to come up with new ideas, improve them, and state their goals and main point (Scardamalia & Bereiter, 1985). However, when researchers used dramatized videotape think-aloud protocols to teach 10-year-olds about types of adult composition planning, including considerations of audience, goals, and organization, the students did not benefit from the instruction (Burtis et al., 1983).

Controlling the use of writing resources in the task environment. There are also likely to be important differences between child and adult novice writers in their ability to orchestrate the use of writing resources. We include among "resources" such elements as dictionaries, thesauruses, personal advice from teachers or writers, and other texts and software (see Figure 1). These differences would be likely to influence the effectiveness of cognitive writing technologies, and research to investigate these issues would be useful for software-design planning.

Age differences may also emerge in a more general way for metatool skills. *Metatool skills* are those skills involved in selecting appropriate technologies for one's specific task, in learning how to use a new tool, and in asking the right questions of the system, of manuals, or of knowledgable helpers. In short, there may be age differences in "tool readiness."

Implications for Computer Writing Tools

There are central lessons from this overview for the designers of cognitive writing technologies. Since writing skills develop, writing technologies must be multilayered and flexibly responsive to a user's current writing skills. Novice writers' diverse problems with different component skills of the writing process imply that the use of expert writing tools by the novice—what we see today—is not in itself likely to improve the novice's writing. Different *entry-level* tools may be required to bring children and adult novices to a skill level where they can maximally benefit from the cognitive writing technologies utilized by experts.

Correlatively, the expert writer is likely to be hindered by tools designed for the child or adult novice's special needs. For example, the explicit prompting provided by word-processing programs, such as CATCH (Daiute, 1983, 1985), INVENT (Burns, 1984), Interactive Text Interpreter (Levin, 1982), QUILL'S PLANNER (Bruce & Rubin, 1984; Collins, in press), SEEN (Schwartz, 1984), WANDAH (Von Blum & Cohen, 1984), and WRITER'S HELPER (Wresch, 1984b), may provide useful devices for encouraging novices to consider whether or not their texts adequately satisfy their stated goals. Wresch (1984a) provides a succinct account of the purposes and kinds of prompted dialogues such programs offer. Explicit prompting may well irritate and distract the experienced writer.

Studies of the Role of Computers in Early Writing

We have outlined sources of difficulties novices have with writing, in terms of the component activities of writing identified in cognitive process models. We now review briefly the few studies of the role of computers in early writing.

Recently, researchers have begun to provide young writers with computer writing tools. Empirical findings are meager at this point, but some promising findings have already emerged. Unfortunately, virtually all studies published to date using word processors or other computer-based writing aids report primarily anecdotal descriptions and case studies of writers, or a class of writers without control comparisons. Daiute (1985) provides the most extensive review of observations of word processing by students of different ages (4–8 years; 9–13 years; high schoolers; college writers). Results from several systematic studies are described below.

What roles do computer writing technologies appear to serve in students' early writing? Many studies document the increased length of student texts when produced by word processors rather than by hand. For example, Levin, Boruta, and Vasconcellos (1983) found that students using a child-oriented text editor called the Writer's Assistant produced longer texts than they produced by hand. Daiute (1985) and Kane (1983) have obtained similar findings. These studies replicate with digital technologies Wood's findings on student writing with typewriters half a century ago.

Do word processors or other writing aids enhance the *quality* of individuals' written compositions? Bruce and Rubin (1984) review evaluation data from the use of the QUILL microcomputer writing system by nearly 100 third- to fifth-grade students. QUILL software (for the Apple II family) includes a text editor and a PLANNER to help children generate and organize ideas for composition, a LIBRARY for storing text files organized by keywords, and a MAILBAG for exchanging messages. They assessed the improvement of students' expository (explanatory) and persuasive writing after 6 months' use of QUILL as compared with matched control groups. QUILL students used the system for at least one-half hour per week. Pretest and posttest writing achievement was measured by primary trait scoring (used in National Assessment of Educational Progress surveys) of experimental and control student writing samples, created off-line. QUILL students' writing improved significantly at all three grade levels and for both forms of writing assessed, and their gains exceeded gains of control students at a statistically significant level in five of six cases. It is important to note that beyond the use of the software, this study included the provision of teacher training for QUILL classroom use, classroom implementation assistance, and follow-up assistance coordinated by a local facilitator. These broader supports are exemplary, since software per se is unlikely to provide an effective instructional treatment.

Bryson, Lindsay, Joram, and Woodruff (1985) investigated the influence of *production-mode* (ICON computer vs. pencil), *task characteristics* (undirected vs. global-organization directed revisions), and *skill level* (average vs. superior writing) on the quality of 16 eighth graders' expository text compositions and text composition processes (assessed through think-aloud protocols). Their findings suggest that writing with computers is not always beneficial for all students under all conditions. They found a significant three-way interaction for skill levels, production-mode, and task characteristics on revised compositions: for *better* students, directed computer revisions led to a significant increase in the holistic and creative quality of their texts, and undirected revisions significantly increased the text scores for stylistic and technical quality. A similar three-way interaction occurred for process measures: better students offered more high-level than low-level justifications for directed revisions when using the computer. Overall quality enhancement due to computer use alone, without respect to condition or skill level of student, was only marginally significant ($p = .07$). The greatest improvements in text quality and sophistication of the writing process arose with better writers, a structured writing task, and the availability of the computer tool.

These two studies suggest that the effects on student writing of word-processing tools may be beneficial, but that the specific consequences may be subtle. We would urge caution in generalizing from these few findings to date.

While we hope for more systematic investigations of the development of writing skills with computer tools, there are many challenges inherent to the task, several of which are noteworthy:

1. New *confounds* are possible since students' difficulties or noneffective instructional treatments may be due to poorly designed writing software, or

misunderstandings by the tool users of how complex computational systems work.

2. No studies to date have investigated long-term effects (even a semester) of novice writing *solely* with computers. Most studies of which we are aware unfortunately involve very few computers (usually one to three per classroom), which students only write with for a few hours per week.

3. Traditionally, the impacts of instructional treatments on writing quality are assessed by paper-and-pencil writing assessments, without student access to the specific aids that accompanied the treatment (Scardamalia & Bereiter, 1985). Although transfer and maintenance measures such as these are important, methodological problems abound in directly importing this feature of previous research to studies of the effects of computer-enhanced writing. Without the technology at hand, there may be dramatically different writing processes set in motion.

4. The social system in which computer writing tools are used—including teacher, peers, audience, and classroom—is likely to have major influences on the effects that these tools have on writing practices (e.g., Bruce, Michaels, & Watson-Gegeo, 1985).

ACTUALIZATION PROBLEMS FOR SUCCESSFUL COGNITIVE WRITING TECHNOLOGIES

Two broad classes of issues must be considered if we are to actualize the potentials of cognitive writing technologies to bridge thinking and writing better. We first describe systems-design concerns that directly affect the *writer* during technology use. Specifically, we outline problems of the cognitive mechanics of writing technology systems. The second class of issues involves *broad contextual* concerns, such as society, school, and family that indirectly but critically affect users of cognitive writing technologies and how they interpret/think about the tools.

Writer-Related Issues in Systems Design

Human psychological factors are primary. The systems design process must be interactive and didactic, playing prototype system characteristics against user reactions and usability (Norman & Draper, 1986). How can the cognitive interface(s) between a writer's creative forces and the computer's writing tool capabilities be best arranged? What are the developmental constraints on the usability of writing systems, and how do these systematically change with writing expertise? Much of the research required to answer these questions will be *parameter testing* in nature. For example, how much user control over plan-cuing options is needed, at what writing skill level? Furthermore, we will need to ask: How will the constraints of the settings in which such tools will be used (e.g., classrooms vs. offices vs. homes) affect their design features (Hawkins & Sheingold, in press)?

Metatool Cognition

What may be the effects of a flood of writing tools for the many different kinds of writing, writing styles, and skill levels? B. Bruce (personal communication, September 1985) has suggested that the writer may face new "metatool" problems; that is, new difficulties will arise as special cognitive skills are required just to know when to use a specific tool. We expect that a plethora of possibilities would be problematic even for highly skilled writers. For novices, we would have to ask when and at what levels of writing skill it would be most useful to introduce specific tools. For example, electronic thesauruses offer on-line access to synonyms. While this tool may be useful for reminding expert writers, who already know the meaning of the related terms, which term more accurately captures the nuances of meaning they wish to convey, it may be inappropriate for novices. This tool alone may not enable novices to evaluate the suitability of words offered by the thesaurus for the meaning they wish to express. Further dictionary capabilities may be required (Miller, 1979).

Maintaining Writing "Ballistics"

It is important that new computer-based writing systems maintain "writing ballistics." An author wants to use transparent writing tools. They should be maximally helpful and, at the same time, unobtrusive and free from distractions; that is, writing choices should take preference over technological choices. This is easier said than done, since solutions to the ballistics problem will likely vary with the writer's skill level. Solving this problem may be particularly difficult in creating cognitive technologies for novice writers who are having enough trouble managing the task of writing without having to contend with the problem of choosing the appropriate tool.

Another potential but (at least, in principle) avoidable danger in creating writing tools for the novice is the use of automated "text critics" that flag textual errors. Too much concern with whether or not one is going to make errors inhibits the creative process, deemphasizes the use of the personal voice in writing, and can hinder writing progress (Elbow, 1981).

Broader Issues: Society, School, and Family

Many issues beyond the "purely cognitive" will affect whether cognitive writing technologies will be viable tools for anyone but their creators. In particular, societal attitudes about writing—and especially their embodiment in our educational system—will decide how cognitive technologies for writing are used. Writing instruction and the ways in which people have learned to write over the centuries have largely determined how people think about writing. How writing activities are currently organized in our schools, at home, in the workplace, or elsewhere also will serve as major constraints on the functionality of cognitive writing technologies. Habits and ways of thinking about writing—when it is done, how, and by whom—will, to some extent, be resistant to change. Furthermore, attitudes toward computational systems will influence the acceptance of computer-based cognitive writing technologies. Although we cannot do justice to these complex issues here, these are *primary* issues to be thought about early enough in the design process to influence the shape of the cognitive writing tools.

In particular, there is the all-important question of the *purpose* and *motivation* of the writer that, as we have seen in our account of the cognitive science of writing, fuels the writing process. These "start-up" issues—what will "propel" writers to begin writing and provide them with the cognitive momentum to keep on writing, to evaluate and revise, or to desire more highly developed writing skills—are at the heart of our broader concerns. In other words, it is one thing to know how to develop writing expertise through cognitive technologies for writing; it is quite another—perhaps even of a different order—to be able to set these processes in motion by getting potential writers onto these developmental tracks.

How can we provide functional learning environments for writing that will attract the novice? How can we encourage the all-important attitude of "trust" in writing—the capacity to tolerate one's own written expression of thoughts and feelings on paper without distorting them to fit some preconceived ideal or fashionable style (Green & Wason, 1982; Wason, 1983)? Researchers and practitioners are making some promising inroads on these problems. Critical links to be forged are those between oral literacy—in which people tend to speak in their own distinctive voice—and written literacy.

We wish to sketch out these levels of broader concern beginning with the *society*, then the *school*, and finally the *family*. These formative forces can serve as either scaffolds or constraints on whether a person who *can* learn to write (and read) does so or not:

> Research . . . suggests that all [physiologically] normal individuals can learn to read and write, provided they have a setting or context in which there is a need to be literate, and they are exposed to literacy, and they get some help from those who are already literate. (Heath, 1980, p. 130)

Society

We need a literate society in which writing and reading are seen as valuable and pleasurable. Such a society would promote the idea of writing not only as expressive but as analytic—something to be critiqued, discussed, reflected upon, and improved. Otherwise there is too little spontaneous reviewing of texts for other than low-level linguistic standards; the writing that develops does not go beyond writer-based prose. Yet these critical activities need to take place in an atmosphere of trust. Texts are not right or wrong, but better or worse in relation to fulfilling the author's goals. Critical judgments are thus seen as part of a constructive interaction between minds (Wason, 1983).

In this society, there would be support systems of listeners, critics, and respondents; in short, a literate community. We should be wary of jumping from "is" to "ought" as some have by observing that "because writing is not often used in our society except by an elite, why encourage it?" For one thing, people might be much more frustrated by their inability to write if they knew the powers it could grant them (Friere, 1970). Most people feel the need to write persuasively throughout life, but feel little connection between what that task calls for and what they learned about writing in school. Insofar as writing is a peripheral activity, it will always need a good deal of instructional support. Writing on computers at home will not happen solely because the computers are there.

Schools

Too often writing instruction consists of copying from blackboards or from teacher dictation (Applebee, 1981). Writing is too infrequently the creative, cyclical, planned, multistaged act we have assumed throughout. There are three primary classes of problems with schools: (1) teachers' attitudes about writing, (2) the status of the child-as-writer, and (3) helping students to mobilize openness and trust in their writing.

1. *Teachers*. One class of problems stems from teachers' attitudes toward and involvement with writing activities. If teachers do not value writing as a cognitive activity in which anyone can engage, why should their students believe they can learn to write well? Not all writing instructors think of themselves as writers, and many do not have available a metalanguage for advising students on the problems they encounter with rhetorical prose. This situation may improve with the increasing use of instructional texts based on cognitive writing research (e.g., Beaugrande, 1982; Flower, 1981). In the meantime, teachers' self-perceptions and misunderstanding of writing processes will inevitably influence their students' reactions to the introduction of cognitive writing technologies in classrooms.

Teachers, as well as children, need a cognitive process model of writing, one that emphasizes the *flexibility* of orchestrating writing subprocesses and the goal that each writer find the writing methods that best suit him or her. This "diversity" model of instruction would give teachers a different attitude about reviewing students' writing; each draft could be seen as one stage in the development of a work, in which students are constructing in their minds the standards of the adult literary world that the teacher implicitly expresses through supportive criticisms.

2. *Child as writer.* The second class of problems has three main aspects, all involving the status of the child-as-writer: the *kinds of writing practiced, writing for effects* on readers, and *writing for voice*.

The kinds of writing children practice is an important issue. More writing activities are needed where children's purposes and interests serve to fuel the writing process. Kenneth Burke (personal communication, September 1983) pleads that people need to get "heated" to write, even "psychotic," in the positive sense of being obsessed with their topic. As one way of embodying these goals, larger literary works such as stories or books could be imagined, discussed, designed, and created by child writers, to make the writing take place over extended periods and be more like writing that occurs in the world beyond the school walls.

Furthermore, like most adults, children need to do writing that, like the oral mode of speech that comes so naturally to them, has *effects*. Student writing should be able to move things or people in the world, rather than merely meeting short-term instructional goals (Smith, 1982). We need to make a greater effort in schools to have a student's goals rather than a teacher's commands serve as engines for writing. As many have recently pointed out, motivating children to write in early writing programs can be facilitated by carrying features of oral communicative contexts into the classroom, such as social interaction and sharing of experiences (Dryson, 1983; Graves, 1975, 1983; Rubin & Bruce, in press; Tannen, 1982). But such expressive writing activities, since they are basically knowledge-telling and do not require goal-related planning, are best viewed as a bridge to other types of writing (Britton, 1982; Scardamalia & Bereiter, 1985). For writing to become *purposeful* and to involve *reflective planning* about goals and goal-directed text creation, more effective interventions need to be introduced, such as strategy instruction, procedural facilitation, product-oriented instruction, and inquiry learning. These approaches are discussed at length by Scardamalia and Bereiter (1985).

There are several activities that demonstrate children's use of computer technologies to write for effects. For example, studies of children's writing on electronic networking systems at the University of California at San Diego demonstrated that when students wrote for a real audience instead of in response to a school assignment, they concentrated much more on formulating messages appropriate to members of the reading audience and their background knowledge (Levin et al., 1983). Riel (1985) found that when students used computers as "functional writing environments," in which an audience had a real interest in the content of their writing, they became actively engaged in revising their own writing and that of their peers. Cohen and Miyake (1985; also see Cohen, Levin & Riel, 1985) describe a worldwide computer network (currently including Israel, Japan, Mexico, Spain, and the United States) they have established where secondary students collaboratively engage in parallel projects in language arts, science, and social studies. Barnhardt (1985) documents experiences in establishing a community of QUILL writing network sites throughout Alaska's remote schools. These computer writing efforts build on earlier efforts to encourage writing across the curriculum for learning (Applebee, 1977; Lehr, 1980).

A third and related aspect of the problem of the status of the child-as-writer is that schools should encourage and value the child's expression of "self" and individuality through his or her writing. A high priority of writing instruction should be to help children to develop their own style and voice. Developing "voice" in writing deserves special emphasis, since it is a quality widely acknowledged to be essential for writing to have "life" and interest—key qualities in capturing a reader's attention and getting effects. Karl Kraus, the masterful Austrian writer and literary critic, illuminated the centrality of voice:

> There are two kinds of writers, those who are and those who aren't. With the first, content and form belong together like soul and body; with the second, they match each other like body and clothes. (Auden & Kronenberger, 1981, p.275)

Problems with attaining and maintaining voice may be exacerbated by software that serves as "critics" of text in terms of such standards as sentence length, word complexity, and other evaluations that lead to a homogeneous writing style. Our cognitive writing technologies should help facilitate rather than restrict the emergence of the writer's distinctive voice. A major way to do this will be to recognize that written voice is rooted in *oral* voice. Burke (personal communication, September 1983) has argued that people should be taught to speak well first and then to write, and that we should then emphasize not only eye-reading from the screen (and page) but voice-reading—going back and forth from the orality of the body to the structures of the written language, so as never to lose the voice of the body "behind" the text (cf. Elbow, 1981).

3. *Openness and trust in writing*. If the first two classes of problems with schools were solved, the third would probably mind itself. Children need, as Wason (1980, 1983; Green & Wason, 1982) has so elegantly argued for novice adult writers, to "mobilize their trust" in their writing, to have confidence in what they say, in the messages of their voices as they develop through their writing. For children to have confidence in their writing processes, they need to know that learning to write takes time, but that with practice, reading of genres, and careful attention to their work and what others say about it, their writing will continue to improve. To feel this confidence, it is important that evaluation, revision, and other writing activities that involve the teacher's tutorial efforts be done in an atmosphere of friendship and collegiality rather than in a reproving, inimical manner. Computer technologies can play only a supportive role to the writing teacher.

Family

We also must point to the family as influential in determining a student's values concerning writing (Heath, 1980, 1981). Although studies of writing development have yet to look seriously at home literacy activities as a research variable, there have been many discussions of how family environments appear to be related to cognitive development (e.g., Walberg & Majoribanks, 1976). If a family considers writing or reading to be important, we expect that children will be more likely to choose to write or find meaning in writing activities.

FUTURE PROSPECTS OF COGNITIVE WRITING TECHNOLOGIES

We have outlined the key difficulties novice adult or child writers encounter and the broader issues that influence writing development. Allusions have been made to ways that software tools might address these problems. We now will speculate on the kinds of cognitive writing technologies that could further serve the creative work of the writer and the learning of writing skills. This question was the focus of a workshop in September 1983 at Bank Street College of Education attended by major writing development researchers and developers of writing technologies, senior cognitive scientists, and literary scholars. Our review and elaboration of suggestions made during this workshop help to define some primary directions for the future development of cognitive writing technologies. We have organized these themes according to the cognitive model of writing processes outlined earlier.

Given the persistence of writer-based prose throughout the school years and throughout life for most writers, what might the new technologies do to help overcome these problems? They could help in:

Planning

Technology can help in all three subprocesses of planning: generating ideas, organizing ideas, and goal-setting.

There are several existing programs that offer templates (or the capability of producing templates) that provide a structure that helps the student generate ideas, organize ideas, and set writing goals.

Generating Ideas

Many students have difficulty coming up with ideas for writing, and recovering from memory what they know already about a given topic. The private and group brainstorming and prewriting activities used in early writing courses (e.g., Boiarsky, 1982) to overcome these obstacles could be supported with computer technologies (Collins, Bruce, & Rubin, 1982). Discovery heuristic prompters and topic browsers are two types of major supports for generating ideas.

1. *Heuristic prompters.* For example, Burns (1984; Burns & Culp, 1980) developed prompting programs to guide college writers in inventing topics for: persuasive writing based on Aristotle's 28 enthymeme topics (TOPOI); journalistic writing based on Burke's "pentad" of scene, action, actor, means, and purpose (BURKE); and exploratory writing based on Young, Becker, and Pike's tagmemic matrix (TAGI) of *particle* (subject in isolation), *wave* (subject as part of a process), and *field* (subject as part of a network). After writing in response to questions from these programs for 30–60 minutes, students may have 10–20 pages of ideas to work with as foundation to their text. Scardamalia & Bereiter (1985) suggest that the common *matrix* or other nonlinear formats for discovery heuristics (e.g., Young, 1976) may help break the novice student's tendency for linear text production.

2. *Topic browsers.* Technologies can help support the writer in thinking of topics and compiling materials for writing. Such technologies would have to build on the logic of question-asking, and recent developments in designing relational database management systems guided by what is known about the progressive refinement character of human memory retrieval processes (Tou, Williams, Fikes, Henderson, & Malone, 1982).

Some suggestive aspects of such a computer tool for scanning electronically stored texts are provided by Weyer's (1982) "interactive book," created at Xerox PARC. It is based on a social studies text and comes with a browser for finding information in the text of specific topics; as a topic is selected, the text on that topic appears, and the relevant words are highlighted.

Interactive videodiscs such as the new Grolier on-line encyclopedia could also be used to provide images and events to spur the discovery of writing topics and facilitate research during prewriting activities. Although they have yet to be put together for writers' use, we now have the key technologies Miller (1979) dreamed of as electronic educational tools: electronic thesaurus, dictionary, and encyclopedia of text and images.

Organizing Ideas

Ultimately, texts need clear structure and organization to guide reader comprehension. Some writers like to begin with high-level structures such as outlines and fill in their text, while others prefer to "freewrite" (Elbow, 1981) and come to discover and then build a structure through these low-level writing activities, which then channels their subsequent writing.

Studies that encourage students to use outlining structures to organize their writing show that they improve student writing quality (Scardamalia & Bereiter, 1983a, 1985). Flexible outlining functions are available when the writer uses outline generating programs that automatically create empty, numbered outline structures inside a word processor (e.g., *Framework II*). Genre-specific writing templates that label outline parts or prompt the writer with specific questions have also been created in some technologies for young writers, such as *QUILL* (Bruce, 1985; Bruce & Rubin, 1984; Collins, in press; Collins, Bruce, & Rubin, 1982; Rubin & Bruce, in press) and the *Interactive Text Interpreter* (Levin, 1982). These templates offer a preestablished structure of parts of specific document types for such forms as haiku poems, business letters, essays, restaurant reviews, and newspaper, weather, and sports stories. Writing to the specifications of the genre within such templates simplifies the idea organization process (Miller, 1985).

The most sophisticated idea organizing system is Xerox PARC's *Notecards*, a multiwindowed authoring system that runs on a minicomputer (Brown, 1985; Collins & Brown, 1986). The writer creates individual notecards that can be defined as multiply indexed ("linked") to other notecards in structures of the writer's invention (e.g., topic tree hierarchy, outline, matrix by source and topic). Cards can contain graphic images (such as a map, or the tree representation of the writer's notecard file), text, or unrefined topical notes. Any kind of links between cards can be defined (e.g., Issue, Argument, Evidence, Counterevidence, for scientific argumentation: Van Lehn, 1985). *Notecards* provides a link-icon browser for the author to skim through notes and their interrelationships. This browser aids an author in finding new structures for text that can be built up around the notecard files. Authors could also do freewriting on a notecard, and later break it up into other notecards that enter into different text structures. Such flexible discovery tools are important because many writers find top-down "outlining" methods too constraining for their writing style (Bridwell, Johnson & Brehe, 1983).

Notecards is an ambitious general notetaking and authoring system that may be too complex for the novice writer. Adaptations of *Notecards* for writers of different levels of skill would be a promising direction. Other promising directions for elaborations in idea organization techniques would be to implement various *heuristic* techniques for organizing ideas. For example, Collins and Gentner (1980) describe seven heuristics for elaborating idea structures: identify dependent variables of an idea; analogize; contrast; imagine scenarios; taxonomize; dimensionalize; and generate extreme cases.

Goal-Setting

Writing has many goals—*rhetorical* goals that determine the effects the writer wishes to have on the reader; *structural* goals that determine the type and form of the text, such as argument or narrative; and *stylistic* goals that determine the devices used in writing, such as metaphor, suspense, and humor (Beaugrande, 1984; Collins & Gentner, 1980). For the purpose of illustration, we limit our discussion to rhetorical goal-setting.

Novice writers need help in specifying the characteristics of their expected audience that will help shape what they say. Often they only have one rhetorical goal for a text (Scardamalia et al., 1984), not many goals that compete, as do expert writers (Flower & Hayes, 1981b). But, when provided with an ending sentence as a goal, students engage in more goal-directed planning during writing (Tetroe et al., in press). We can imagine heuristic prompting guides in writing software that would solicit multiple-goal descriptions: of *effects* the writer would like to have on readers (e.g., making the text enticing, persuasive, memorable, comprehensible: Collins & Gentner, 1980), the *background knowledge* different *types* of readers would need for these effects to occur, and other audience considerations (Rubin, 1983).

There is also promise in computer-enhanced versions of recent intervention studies that directly instruct dialectical strategies of *synthesizing* competing rhetorical goals and main ideas, suggesting the availability of these important reflective processes even in sixth graders (Scardamalia et al., 1984; Scardamalia & Bereiter, in press). With such guides, perhaps novice writers could better learn to define their rhetorical problem and high-level writing purposes and goals.

Translating

Translating is the process of putting thought into text, subject to linguistic and pragmatic constraints. At a microlevel, translations are closely articulated with the writing subprocesses of planning, reviewing, and monitoring. The primary role for technologies here is "lubricating" the motor entry of ideas as text through the computer's input device. Macro capabilities and phrase expanders are two computer supports for streamlining the translation process. Many writing systems now allow the user to define large numbers of "macros," user-defined sequences of keystrokes that can be executed with 1–2 keystrokes. Phrase expanders such as the "library" facility in *Framework* let the writer define 2-keystroke abbreviations of commonly used long words or phrases. Major advances are in store once the sophisticated systems that allow direct speech rather than keyboard input become commonly available. (The Committee on Computerized Speech Recognition established by the National Research Council [1984] has provided an authoritative survey of state-of-the-art speech recognition programs.) It has been found that it is the greater *speed* of dictation over writing, not the decrement in mechanical effort, that contributes to the greater amount of text young writers produce when dictating (Scardamalia et al., 1982). This dictation effect disappears for skilled adult writers (Gould, 1980).

Reviewing

Computers can help with both the evaluating and revising subprocesses to the mental activity of reviewing already-written text. They can also play an integral role in motivating the review process, and encouraging different types of revision. Computer telecommunication networks have been effectively used to support peer feedback on writing, and thus better motivate the writing and revising process for interpersonal communications (Levin & Boruta, in press; Levin, Boruta, & Vasconcellos, 1983; Levin, Riel, Rowe, & Boruta, 1985; Riel, 1983, 1985). The use of revision checklists, which list different types of revisions to be made, improves student writing quality (Scardamalia & Bereiter, 1983a, 1985). Collins and Gentner (1980) offer a succinct list of text-level, paragraph-level, and sentence-level editing operations that could guide the writer as valuable on-line reminders.

Evaluating

Evaluation of ongoing text can be supported in various ways. To evaluate one's text, the writer first needs to be able to *read* it well, and then various "critics" can be applied to the text, whose different analyses the writer can ignore or accept by revising accordingly.

1. *Rereading facilitators.* Technologies could be created that re-present an author's text in order to simplify its reading. This need is highlighted by the recent discovery of the importance of screen text format design for *local* ease of reading comprehension. Frase, MacDonald, and Keenan (1985) discuss developments in computer-aided text format design that allow segmentation and grouping of psycholinguistically defined "chunks" of text on lines that are easier for readers to remember and read (Frase & Schwartz, 1979; Hartley, 1981). Such improvements are likely to facilitate the writer's processes of revision.

More substantive problems exist for *global* processing of text structures displayed on screens. Haas and Hayes (in press) have documented difficulties even experienced computer-writers have in locating information, detecting errors, and in critically reading their texts when reading screen-based rather than hardcopy text (also see Gould & Gribschkowky, 1984; Wright & Lickorish, 1983). However, Haas and Hayes found that large screen size (SUN workstation with a 19-inch diagonal screen of 50 lines by 90 characters, rather than the standard screen display of 23 lines by 99 characters) approached hard copy for text-processing efficiency.

2. *Evaluation aids.* Writers now have available a broad range of types of critical help on their texts, from spelling to grammar and some elements of style. As discussed earlier, *UNIX WRITER'S WORKBENCH* and *Epistle* are the most sophisticated systems available. These systems have primarily been used in business settings and not in precollege education. They may help novice writers catch many typical writing mistakes, but only when they are used and tested in educational settings will we know more about what new critical facilities would be useful.

3. *Genre model comparators.* Reading to write and writing to read are important reciprocal relations that are central to the development of writing skills. Databases of model examples of different writing genres could be created, and reading such sources and emulating their writing style could provide novice writers with valuable experience. Research on extracting literary knowledge of stylistic features from examples of different genres suggests the promise of electronic tools for young students learning to write to genre specifications (Church & Bereiter, in press; unpublished work cited in Scardamalia & Bereiter, 1985). Writers could make specific comparisons of their versions with genre models by means of language analysis tools available, for example, on the WRITER'S WORKBENCH system (Frase, 1984).

4. *Critical dialogue annotators.* Writing process conferences between teacher and student and other instructional contexts where the teacher plays a collaborative writing role as "substantive facilitator" (Bereiter & Scardamalia, 1982) are proving to be powerful environments for learning to write (Calkins, 1986; Graves, 1983). But this dialogue takes place today without additional computer support. Annotation tools are needed to help organize the on-line equivalent to the conversational "What do you mean?" by logging the critical suggestions and questions the teacher or fellow students make on a student's computer-created text (Brown, 1985). In this way, students could refine their text through the dialogic process familiar from spoken discourse. The QUILL Mailbag program has been used for commentary on student writing (Bruce & Rubin, 1984) with the QUILL text editor, but the two programs are not integrated.

5. *Expert text critics.* Today natural language understanding by computers is relatively primitive, and the problems highly complex, but advances by artificial intelligence on language comprehension will have important implications for the types of feedback and critique computers can offer the writer. Even now, genre-specific stylistic analyses of texts are beginning to appear (IBM's *Epistle:* Miller, 1985).

Revising

Authors often need to revise text, but they also need to revise main and subsidiary ideas, goals, and organizational structures in the text beyond the word and sentence, such as the paragraph or entire text (Beaugrande, 1984; Bruce et al., 1982; Collins & Gentner, 1980; Frederiksen, 1983). For example, schematic argument structures are preeminent for expository writing—the working structure of the literature of law, philosophy, science, and the classic essay form. The familiar text structure is introduction, background, issue definition, statement of thesis to be proven, arguments for and against the thesis, refutation of opposing arguments, and summation (Lanham, 1969). Other text-level forms that could be supported by specific modes of a writing system are the "pyramid form" found in news stories, and "narrative forms," which have been the focus of psycholinguistic research on story grammars (e.g., Mandler & Johnson, 1977). Software could be created to help reflect back to the writer the text created thus far at representational levels not previously accessible without great effort (e.g., topical outlining, argument structures, decision paths, networks, issue trees: Collins & Brown, 1986).

There are also many different methods of text revision available (Elbow, 1981), and the writer could have electronic reminders of these methods with examples available on-line while writing.

Monitoring

Two major monitoring problems novice writers have are monitoring progress toward their writing goals, and trying to carry out too many of the component mental activities in writing, such as planning, translating, and reviewing, all at once.

Writing systems such as *QUILL* suggest one approach to these problems, in which different program modules are used for the different writing process activities, e.g., Planning and Translating. Students can return to *QUILL*'s *Planner* to check their writing goal and, if it has changed, to revise it. The explicit division of writing system functions alleviates the mental burden of maintaining goals in memory during the writing process. Ideally, these different functions could be simultaneously displayed as windows on the screen and always be available to the writer. In this way, the computer tool would literally serve as an extended memory buffer for the information processing capabilities of the writer (Pea, 1985).

New Technologies That Facilitate Many Writing Subprocesses

Some computer tools we can envision would facilitate the entire writing process, or at least many of its subprocesses.

First, there are many roles for a writing system that preserves the *revisionary history* of a written document. Such process-oriented writing tools could be created today (Brown's *ANNOLAND*, 1985), would be very helpful for teachers and researchers, and could be useful for the writer if contexted appropriately. One could unpeel successive layers of revisions in efforts to understand how a text structure is built, deconstructed, and rebuilt, or to find text segments in earlier drafts that were deleted and later found to be usable. Collins and Brown (1986, p. 10) note how students could observe and analyze abstracted replays of their own or others' writing processes. They recommend abstracted replays at the level of "notes, outlines, browsers, and paragraph headings as elements in conjunction with operators such as rearrangement, deletion and annotation."

Second, we need tools that better enable collaborative *group writing*, in all of its phases from topic brainstorming to final revisions. Many of the computer-based writing projects in classrooms have observed that children enjoy collaborative writing at the computer, and appear to engage in more high-level planning and revision talk about document structure than without the computer (Dickinson, 1985). Writing tools expressly aimed at promoting group writing and critique are just now beginning to appear (e.g., *For-Comment, Docuforum*)

Finally, we very much need the expensive-to-develop *general resource tools*—for example, electronic dictionaries, thesauruses, grammars and text parsers, image and text encyclopedias, electronic text banks of good and bad examples of different writing genres, and other useful graphic and textual databases—that would provide a substratum upon which many different kinds of cognitive writing technologies could be built. While programs such as *Turbo Lightning* are a step in this direction, of particular utility would be automated dictionaries, organized for use during writing in ways compatible with human processes of lexical access (e.g., in terms of semantic networks of relations), unlike today's dictionaries (Miller, 1979).

Educational Uses of Computers for Writing

Explicit Instruction

We have highlighted the need for cognitive writing technologies that *directly* support the component activities of the writing process, and help writers develop writing and thinking skills under their control. Along the continuum from such learning through writing to formal education on writing, computers can also be used for explicit instruction in writing processes. In particular, they could teach new writing strategies rather than supporting the writer's refinement of those strategies already available. A few powerful approaches may be described.

One could directly instruct the techniques used by expert writers by building programs that take standard writing assignments and display through think-aloud protocols (with textual or speech synthesis overlays) the kinds of decision-making and use of strategies that good writers use during the writing process. The goal would be to raise novice writers' awareness of writing processes—especially their cyclical rather than linear nature—and increase their repertoire of writing and revising methods. For example, with an interactive videodisc we could exemplify key writing processes at major decision points by creating docudramas of a real writer, who articulates aloud his or her metacognitive activities as he or she plans, translates, reviews, and monitors. Writers of different skill levels could be represented and their sessions explored and analyzed by the writing student. In short, we want technologies that, for instructional purposes, can make the cognitive processes of better writing more "visible" for analysis, imitation, and internalization. Similar recommendations have been offered for teaching reading comprehension skills (Collins & Smith, 1982), and preliminary studies have used videotape writing process "displays" (Burtis et al., 1983).

Writing Games

Computer versions of games could be produced that induce rhetorical goal setting, or other writing activities that are beyond a writer's current approach to writing and could reasonably lead to an advance in his or her writing skills. For example, Scardamalia, Bereiter, and Fillion (1981) have shown the effectiveness of writing games that provide various kinds of final sentences to give students a goal to work towards. New interactive fiction programs, although less directive, involve the player in a form of "coauthoring" (Adams, 1985).

Existing computer games for writing include: *StoryMaker,* which provides sentences that the writer can sequence for preferred event sequences (Rubin, 1980); *EXPLORE,* where the writer only makes structural and stylistic decisions, the computer filling in the rest (Woodruff, Scardamalia, & Bereiter, 1982); *StoryMachine,* in which beginning writers can construct four-sentence stories from 40 sight vocabulary words, and see the stories acted out graphically on the screen, and *Writing Adventure,* in which students are prompted to take notes and write observations as they move through a standard adventure game format.

NEEDED DIRECTIONS IN RESEARCH FOR COGNITIVE WRITING TOOLS

It should be clear that we regard as the major issues surrounding the development of cognitive writing technologies those that focus on the *person* writing, not the technology per se. This seems self-evident to us, but current practices and research topics suggest otherwise. While some human factors research is needed to better ascertain what ideal screen layouts, keyboard configurations, or command structures people can most easily or effectively use, the most important issues center on what the developing writer knows or understands about writing, not the technology's intrinsic capabilities. The goal of *symbiosis*—how to best create the productive union of humans and machines to serve our developmental advancements—will become our critical research topic (e.g., Pea, 1985; Woods, 1986).

There are several major issues for research in the near future that we believe could significantly shape future cognitive writing technology systems design. A particularly high research priority is the detailed investigation of developmental processes within and between various components of writing skills, and the specific roles different writing technologies can play in directly facilitating these processes. In our brief historical introduction, we characterized current explorations of *direct* supports for the different cognitive activities of writing as characteristic of a new, fourth phase in the genesis of electronic writing tools. The step-by-step list of tool recommendations in terms of the cognitive process model earlier presented is in the spirit of this fourth phase.

At the same time, we eagerly await a "fifth generation" of tightly integrated "adaptive" writing systems that support all the phases of a writer's thinking and writing, changing in response to developmental needs and the writer's redefinitions of supports found useful throughout the decades of writing skill development.

We also hope research on writing development with computer tools moves beyond *descriptive* studies of a *few* students working *sometimes* with word processors as *stand-alone* systems. Future work will involve model-testing, large-scale, and long-term studies of students using sophisticated authoring systems as their main instruments of writing, which serve more broadly as communication tools, linked by telecommunications to other schools and writers that can serve as an extended community of "literary critics." In these broader studies, more fine-grained text analytic techniques, derived from psycholinguistics and stylistics, need to be used to trace comparative improvements in students' writings. Beyond these basic concerns, one other area seems especially worthy of research attention.

Since cognitive writing technologies, as we have argued, are likely to require good writing instructors to be effective, we need to discover what superior writing teachers and critics in fact *do* to improve a student's writing. What are the practices of a good writing instructor? Outcomes of such studies will be needed to inform the design of future "expert" and "intelligent" systems for computer-assisted writing instruction, and possibly the computer-based textual critics that will encourage further development of expert writers' skills.

We are encouraged by the Socratic system for tutoring causal knowledge and reasoning developed by Collins and Stevens (1982), which incorporated rules for tutorial interactions derived from careful observations of the dialogues of expert inquiry teachers. To adapt these techniques to writing, complex problems in delivering the coaching feedback offered by the system will need to be solved. Sleeman & Brown (1982) provide a rich description of these problems in the design of intelligent tutoring systems. Generalizing from their cautions, we would expect that too much or untimely feedback could hinder the writing process.

We do not know if these same issues will apply to the expert writer using cognitive writing technologies. We know little about how such mature writers continue to improve their writing skills, yet analyses of literary development among writers, poets, and philosophers are commonplace in the critical literature of the humanities. How are such advances accomplished? How could they be encouraged by design features of computer-based writing technologies? Once the cognitive supports of various component processes of writing are provided, expert writers may be able to discover for themselves how to use them to improve their writing, just as scientists offered new tools of mathematical analysis can define and solve new problems.

CODA

We have highlighted what promise to be productive directions in the growing collaboration between those who study how writing skills develop and those who create computer writing tools. Just as importantly, we have described how tools reside in a complex "ecological niche" of family, school, and societal influences that must be considered if we are to end up with writing technologies that can be used effectively, particularly in the formative years of writing education.

At least four major classes of influences need to be considered: (1) the current writing skills of an individual, and the structure and function of his or her component cognitive processes while engaged in writing; (2) the affective-motivational complex that defines an individual's attitudes toward and interest in writing activities; (3) the instructional environment—including specific instructional tasks, attitudes and interventions of teachers, peers, and the larger framework of society; and (4) the writing technologies, including computer tools, that are available. Very little work thus far has addressed the terrain of writing development in those terms, and writing research from such a systems orientation brings new methodological challenges. Yet as Bruce and his colleagues (1985, p. 147) observe: "The most important impact of microcomputers on writing may be changes in the larger classroom writing "system" rather than changes in the technology of writing."

Although tools have been our major focus, forging new computer technologies that strengthen the various cognitive processes central to developing good writing is but one part of the equation linking writers to better writing. Teachers need to know more about how to foster writing processes, whether or not they have new technologies available. The literacy practices and attitudes of society and parents may also be sending students significant (and mixed) messages about the importance of good writing. And the affective and motivational side of writing activities, although little studied, appears to play a major role in the attainment of writing voice, and whether writing practices are even begun.

Writing is an intricate and important cognitive and educational problem that is finally beginning to attract the scientific attention it warrants. The imbalanced focus on how people learn to read existing texts, rather than on how they can create their own, is at last shifting. Using the symbolic capabilities of the computer to serve writing development promises to be one of the most exciting and truly *personal* uses of the computer. If, as Wittgenstein noted, writing can help ideas develop, computers can help writers develop their ideas by directly supporting the activities ingredient to writing. We think there is reason to be optimistic about the dialogues on writing that are beginning to take place among software designers, writers, psychologists, linguists, and

educators, and we expect that they will lead to a deeper understanding of how best to use computer tools to create cognitive writing technologies.

REFERENCES

Adams, S. (1985, March). Interactive fiction. *Popular Computing*, 97–99, 180–182.

Applebee, A.N. (1977). ERIC/RCS Report. Writing across the curriculum: The London projects. *English Journal, 66*(9), 81–85.

Applebee, A.N. (1981). *Writing in the secondary school.* Research Monograph No. 21. Urbana, IL: National Council of Teachers of English.

Auden, W.H., & Kronenberger, L. (1981). *The Viking book of aphorisms: A personal selection.* New York: Penguin.

Barnhardt, C. (1985). The Quill microcomputer writing program in Alaska. In R.V. Dusseldorp (Ed.), *Alaska's challenge: Computers in education strategies and solutions.* Anchorage: Alaska Association for Computers in Education.

Barthes, R. (1982). Authors and writers. In S. Sontag (Ed.), *A Barthes reader* (pp. 185–193). New York: Hill & Wang. (Originally published in 1960)

Beaugrande, R. de (1982). *Writing step by step.* Gainesville: University of Florida Office on Instructional Resources.

Beaugrande, R. de (1984). *Text production: Toward a science of composition.* Norwood, NJ: Ablex.

Bereiter, C. (1980). Development in writing. In L.W. Gregg & E.R. Steinberg (Eds.), *Cognitive processes in writing.* Hillsdale, NJ: Erlbaum.

Bereiter, C., & Scardamalia, M. (1982). From conversation to composition: The role of instruction in a developmental process. In R. Glaser (Ed.), *Advances in instructional psychology* (Vol. 2, pp. 1–64). Hillsdale, NJ: Erlbaum.

Bereiter, C., & Scardamalia, M. (1983a). Does learning to write have to be so difficult? In A. Freedman, I. Pringle, & J. Yalden (Eds.). *Learning to write: First language, second language* (pp. 20–33). London: Longman's International.

Bereiter, C. & Scardamalia, M. (1983b) Levels of inquiry in writing research. In P. Rosenthal, S. Walmsley, & L. Tamor (Eds.), *Research in writing: Principles and methods* (pp. 3–25). New York: Longman International.

Bereiter, C., & Scardamalia, M. (1985). Cognitive coping strategies and the problem of "inert knowledge." In S. Chipman, J.W. Segal, & R. Glaser (Eds.), *Thinking and learning skills: Current research and open questions* (Vol. 2, pp. 65–80). Hillsdale, NJ: Erlbaum.

Boiarsky, C. (1982). Prewriting as the essence of writing. *English Journal, 71*(4), 44–47.

Bracewell, R.J. (1980). Writing as a cognitive activity. *Visible Language, 14*, 400–422.

Bracewell, R.J., Frederiksen, C.H., & Frederiksen, J.D. (1982). Cognitive processes in composing and comprehending discourse. *Educational Psychologist, 17*(3), 146–164.

Bridwell, L.S., Johnson, P., & Brehe, S. (1983). Computers and composing: Case studies of experienced writers. In A. Matsuhashi (Ed.), *Writing in real time: Modelling production processes.* New York: Longman.

Britton, J. (1982). Spectator role and the beginnings of writing. In M. Nystrand (Ed.), *What writers know: The language, process, and structure of written discourse* (pp. 149–169). New York: Academic Press.

Brown, J.S. (1982, July). *Notes concerning desired functionality, issues, and philosophy for an AuthoringLand.* Palo Alto, CA: Xerox Palo Alto Research Center.

Brown, J.S. (1984). *Idea amplifiers: New kinds of electronic learning environments.* Palo Alto, CA: Xerox Palo Alto Research Center.
Brown, J.S. (1985). Process versus product: A perspective on tools for communal and informal electronic learning. *Journal of Educational Computing Research, 1,* 179–201.
Bruce, B.C. (1985, June). *An examination of the role of computers in teaching language and literature.* Technical Report. Cambridge, MA: Bolt, Beranek & Newman.
Bruce, B., Collins, A., Rubins, A.D., & Gentner, D. (1982). Three perspectives on writing. *Educational Psychologist, 17*(3), 131–145.
Bruce, B., Michaels, S., & Watson-Gegeo, K. (1985). How computers can change the writing process. *Language Arts, 62,* 143–149.
Bruce, B., & Rubin, A. (1984). *The utilization of technology in the development of basic skills instruction: Written communications. Final report: Volume 1.* Technical Report No. 5766. Cambridge, MA: Bolt, Beranek & Newman.
Bruner, J.S., & Olson, D.R. (1977–1978). Symbols and texts as the tools of intellect. *Interchange, 8*(4), 1–15.
Bruner, J.S., Olver, R., Greenfield, P.G., Hornsby, J., Kenney, H., Maccoby, M., Modiano, H., Mosher, F., Olson, D., Potter, M., Reisch, L., & Sonstroem, A. (1966). *Studies in cognitive growth.* New York: Wiley.
Bryson, M., Lindsay, P.H., Joram, E., & Woodruff, E. (1985). *Augmented word-processing: The influence of task characteristics and mode of production on writers' cognitions.* Toronto: Ontario Institute for Studies in Education.
Burke, K. (1950). *A rhetoric of motives.* Englewood Cliffs, NJ: Prentice-Hall.
Burns, H. (1984). Recollections of first-generation computer-assisted prewriting. In W. Wresch (Ed.), *The computer in composition instruction: A writer's tool* (pp. 15–33). Urbana, IL: National Council of Teachers of English.
Burns, H.L., & Culp, G.H. (1980). Stimulating invention in English composition through computer-assisted instruction. *Educational Technology, 20*(8), 5–10.
Burtis, P.J., Bereiter, C., Scardamalia, M., & Tetroe, J. (1983). The development of planning in writing. In C.G. Wells & B. Kroll (Eds.), *Explorations of children's development in writing* (pp. 153–174). Chichester, England: John Wiley.
Butturff, D.R., & Sommers, N.I. (1980). Placing revision in a reinvented rhetorical tradition. In A. Freedman & I. Pringle (Eds.), *Reinventing the rhetorical tradition.* Urbana, IL: National Council of Teachers of English.
Caccamise, D.J. (1985). Idea generation in writing. In A. Matsuhashi (Ed.), *Writing in real time: Modelling production processes.* New York: Longman's International.
Calkins, L.M. (1986). *The art of teaching writing.* Portsmouth, NH: Heinemann.
Case, R. (1985). *Intellectual development: Birth to adulthood.* New York: Academic Press.
Church, E., & Bereiter, C. (in press). Reading for style. *Language Arts.*
Cohen, M., Levin, J.A., & Riel, M.M. (1985). *The world as functional learning environment: An intercultural learning network.* Technical Report, Interactive Technology Laboratory, Center for Human Information Processing. La Jolla: University of California, San Diego.
Cohen, M., & Miyake, N. (1985). *A worldwide intercultural network: Exploring electronic messaging for instruction.* Report No. 8, Interactive Technology Laboratory, Center for Human Information Processing. La Jolla: University of California, San Diego.
Collins, A. (in press). Teaching reading and writing with personal computers. In J. Orasanu (Ed.), *A decade of reading research: Implications for practice.* Hillsdale, NJ: Erlbaum.

Collins, A., & Brown, J.S. (1986). *The computer as a tool for learning through reflection.* Technical Report. Cambridge, MA: Bolt, Beranek & Newman.
Collins, A., Bruce, B.C., & Rubin, A. (1982). Microcomputer-based writing activities for the upper elementary grades. In *Proceedings of the Fourth International Learning Technology Congress and Exposition* (pp. 134–140). Warrenton, VA: Society for Applied Learning Technology.
Collins, A., & Gentner, D. (1980). A framework for a cognitive theory of writing. In L.W. Gregg & E.R. Steinberg (Eds.), *Cognitive processes in writing* (pp. 51–72). Hillsdale, NJ: Erlbaum.
Collins, A., & Smith, E.E. (1982). Teaching the process of reading comprehension. In D.K. Detterman & R.J. Sternberg (Eds.), *How much and how can intelligence be increased?* (pp. 173–185). Norwood, NJ: Ablex.
Collins, A., & Stevens, A. (1982). Goals and strategies of inquiry teachers. In R. Glaser (Ed.), *Advances in instructional psychology* (Vol. II, pp. 65–119). Hillsdale, NJ: Erlbaum.
Committee on Computerized Speech Recognition (1984). *Automatic speech recognition in severe environments.* Report from National Research Council, Committee on Engineering and Technical Systems. Washington, DC: National Academy Press.
Cooper, C.R., & Matsuhashi, A. (1983). A theory of the writing process. In M. Martlew (Ed.), *The psychology of written language: A developmental approach* (pp. 3–39). London: Wiley.
Cooper, L. (1932). *The rhetoric of Aristotle.* Englewood Cliffs, NJ: Prentice-Hall.
Daiute, C. (1983, April). *The effects of automatic prompting on young writers.* Paper presented at the Annual Meeting of the American Educational Research Association, Montreal, Canada.
Daiute, C. (1985). *Writing and computers.* Reading, MA: Addison-Wesley.
Damon, W. (1979). *The social world of the child.* San Francisco: Jossey-Bass.
Dickinson, D.K. (1985). *Young children's collaborative writing at the computer.* Paper presented at the annual meeting of the American Educational Research Association, Chicago.
Drury, M.O. (1982). Conversations with Wittgenstein. In R. Rhees (Ed.), *Ludwig Wittgenstein: Personal recollections.* Oxford: Blackwell.
Dyson, A.H. (1983). The role of spoken language in early writing processes. *Language Arts, 60*(2), 234–243.
Eisenstein, E.L. (1979). *The printing press as an agent of change.* New York: Cambridge University Press.
Elbow, P. (1981). *Writing with power: Techniques for mastering the writing process.* New York: Oxford University Press.
Elbow, P. (1983, September). Teaching thinking by teaching writing. *Change,* 37–40.
Faigley, L., & Witte, S. (1981). Analyzing revision. *College Composition and Communication, 32,* 400–414.
Flower, L. (1979). Writer-based prose: A cognitive basis for problems in writing. *College English, 41*(1), 18–37.
Flower, L. (1981). *Problem-solving strategies for writing.* New York: Harcourt Brace Jovanovich.
Flower, L., & Hayes, J.R. (1980a). The cognition of discovery: Defining a rhetorical problem. *College Composition and Communication, 31,* 21–32.
Flower, L.S., & Hayes, J.R. (1980b). The dynamics of composing: Making plans and juggling constraints. In L.W. Gregg & E.R. Steinberg (Eds.), *Cognitive processes in writing* (pp. 31–50). Hillsdale, NJ: Erlbaum.

Flower, L., & Hayes, J.R. (1981a). A cognitive process theory of writing. *College Composition and Communication, 32*, 365–387.
Flower, L., & Hayes, J.R. (1981b). The pregnant pause: An inquiry into the nature of planning. *Research in the Teaching of English, 15*, 229–244.
Flower, L., & Hayes, J.R. (1984). Images, plans, and prose: The representation of meaning in writing. *Written Communication, 1*(1), 120–160.
Frase, L.T. (1983). The UNIX™ Writer's Workbench software: Philosophy. *The Bell System Technical Journal, 62*(6), 1883–1889.
Frase, L.T. (1984). Knowledge, information, and action: Requirements for automated writing instruction. *Journal of Computer-Based Research, 11*(2), 55–59.
Frase, L.T. (in press). Technology, reading, and writing. In J. Squire (Ed.), *The dynamics of language learning: Research in the language arts.* Urbana, IL: National Council of Teachers of English-ERIC Center.
Frase, L.T., Macdonald, N.H., & Keenan, S.A. (1985). Intuitions, algorithms, and a science of text design. In T.M. Duffy & R. Waller (Eds.), *Designing usable texts* (pp. 97–112). New York: Academic Press.
Frase, L.T., & Schwartz, B.J. (1979). Typographical cues that facilitate comprehension. *Journal of Educational Psychology, 71*, 197–206.
Frederiksen, C.H. (1983). *Writing as structure-building: Notes toward a cognitive theory of text production (with observations on instruction).* Unpublished manuscript, Department of Psychology, McGill University, Montreal, Canada.
Friere, P. (1970). *Cultural action for freedom* (Monograph Series No. 1). Cambridge, MA: Harvard Graduate School Center for the Study of Development and Social Change.
Gagné, R.M., & Dick, W. (1983). Instructional psychology. *Annual Review of Psychology, 34*, 261–295.
Glaser, R. (1982). Instructional psychology: Past, present and future. *American Psychologist, 37*(2), 292–305.
Goody, J. (1977). *The domestication of the savage mind.* New York: Cambridge University Press.
Gould, J.D. (1980). Composing letters with computer-based text editors. *Human Factors, 23(5)*, 593–606.
Gould, J.D., & Gribschkowky, N. (1984). Doing the same work with hard copy and with CRT terminals. *Human Factors, 26*, 323–337.
Graves, D.H. (1975). An examination of the writing processes of seven-year-old children. *Research in the Teaching of English, 9*, 227–241.
Graves, D.H. (1983). *Writing: Teachers and children at work.* Exeter, NH: Heinemann Educational Books.
Green, D.W., & Wason, P.C. (1982). Notes on the psychology of writing. *Human Relations, 35*, 47–56.
Greenfield, P.M. (1972). Oral and written language: The consequences for cognitive development in Africa, the United States, and England. *Language and Speech, 15*, 169–178.
Greeno, J.G., & Simon, H.A. (in press). Problem solving and reasoning. In R.C. Atkinson, R. Herrnstein, G. Lindzey, & R.D. Luce (Eds.), *Stevens' handbook of experimental psychology* (rev. ed.). New York: Wiley.
Gregg, L.W., & Steinberg, E.R. (Eds.). (1980). *Cognitive processes in writing.* Hillsdale, NJ: Erlbaum.
Gross, J. (Selector). (1983). *The Oxford book of aphorisms.* Oxford: Oxford University Press.

Haas, C., & Hayes, J.R. (in press). What did I just say? Reading problems in writing with the machine. *Research in the Teaching of English.*
Hartley, J. (1981). Eighty ways of improving instructional text. *IEEE Transactions on Professional Communication, PC-24*, 17–27.
Havelock, E.A. (1963). *Preface to Plato.* Cambridge, MA: Harvard University Press.
Hawkins, J., & Sheingold, K. (in press). The beginning of a story: Computers and the organization of learning in classrooms. In J. Culbertson & L.L. Cunningham (Eds.), *Uses of microcomputers and other technology in education.* Chicago: University of Chicago Press.
Hayes, J.R., & Flower, L.S. (1980a). Identifying the organization of the writing process. In L.W. Gregg & E.R. Steinberg (Eds.), *Cognitive processes in writing* (pp. 3–30). Hillsdale, NJ: Erlbaum.
Hayes, J.R., & Flower, L.S. (1980b). Writing as problem solving. *Visible Language, 14*(4), 388–399.
Heath, S.B. (1980). The functions and uses of literacy. *Journal of Communication, 30*, 123–133.
Heath, S.B. (1981). Toward an ethnohistory of writing in American education. In M.F. Whiteman (Ed.), *Writing: The nature, development, and teaching of written communication. Vol 1: Variation in writing: Functional and linguistic cultural differences* (pp. 25–45). Hillsdale, NJ: Erlbaum.
Heidorn, G.E., Jensen, K., Miller, L.A., Byrd, R.J., & Chodorow, M.S. (1982). The EPISTLE text-critiquing system. *IBM Systems Journal, 21*(3), 305–325.
Kane, J.H. (1983). *Computers for composing.* Technical Report No. 13, Center for Children and Technology. New York: Bank Street College of Education.
Keil, F.C. (1979). *Semantic and conceptual development.* Cambridge, MA: Harvard University Press.
Kroll, B. (1978). Cognitive egocentrism and the problem of audience awareness in written discourse. *Research in the Teaching of English, 12*, 269–281.
Lanham, R.A. (1969). *A handlist of rhetorical terms.* Berkeley: University of California Press.
Lanham, R.A. (1979). *Revising prose.* New York: Scribners.
Larson, R. (1971). Toward a linear rhetoric of the essay. *College Composition and Communication, 22*, 140–145.
Lehr, F. (1980). ERIC/RCS report: Writing as learning in the content areas. *English Journal, 69*(8), 23–25.
Levin, J.A. (1982). Microcomputers as interactive communication media: An interactive text interpreter. *Quarterly Newsletter of the Laboratory of Comparative Human Cognition, 4*, 34–36.
Levin, J.A., & Boruta, M.J. (in press). Writing with computers in classrooms: "You get EXACTLY the right amount of space!" *Theory into Practice.*
Levin, J.A., Boruta, M.J., & Vasconcellos, M.T. (1983). Microcomputer-based environments for writing: A writer's assistant. In A.C. Wilkinson (Ed.), *Classroom computers and cognitive science* (pp. 219–232). New York: Academic Press.
Levin, J.A., Riel, M.M., Rowe, R.D., & Boruta, M.J. (1985). Muktuk meets Jacuzzi: Computer networks and elementary school writers. In S.W. Freedman (Ed.), *The acquisition of written languages: Revision and response.* Hillsdale, NJ: Erlbaum.
Macdonald, N.H. (1983). The UNIX™ Writer's Workbench software: Rationale and design. *The Bell System Technical Journal, 62*(6), 1891–1908.

Maimon, E. (1979). Talking to strangers. *College Composition and Communication, 30,* 364–369.
Mandler, J.M., & Johnson, N.S. (1977). Remembrance of things parsed: Story structure and recall. *Cognitive Psychology, 9,* 111–151.
McCutchen, D., & Perfetti, C.A. (1982). Coherence and connectedness in the development of discourse production. *Text, 2,* 113–139.
Mehan, H., Moll, L., & Riel, M.M. (1985). *Computers in classrooms: A quasi-experiment in guided change.* (Final Report, NIE 6–83–0027). San Diego: University of California, San Diego.
Miller, G.A. (1979). Automated dictionaries. In R.W. Tyler & S.H. White (Eds.), *Testing, teaching and learning* (pp. 180–184). Washington, DC: National Institute of Education.
Miller, G.A., & Johnson-Laird, P.N. (1976). *Language and perception.* Cambridge, MA: Harvard University Press.
Miller, L.A. (1985, July). Computers for composition: A stage model approach to helping. *IBM Research Report, Computer Science,* #RC 11261.
Murray, D.M. (1978). Internal revision: A process of discovery. In C.R. Cooper & L. Odell (Eds.), *Research on composing.* Urbana, IL: National Council of Teachers of English.
Murray, D.M. (1980). How writing finds its own meaning. In T.R. Donovan & B.W. McClelland (Eds.), *Teaching composition: Theory into practice.* Urbana, IL: National Council of Teachers of English.
Newell, A., & Simon, H.A. (1972). *Human problem solving.* Englewood Cliffs, NJ: Prentice-Hall.
Nold, E.W. (1982). Revising. In C.H. Frederiksen, M.F. Whiteman, & J.F. Dominic (Eds.). *Writing: The nature, development, and teaching of written communication.* Hillsdale, NJ: Erlbaum.
Norman, D.A., & Draper, S.W. (Eds.). (1986). *User centered system design: New perspectives in human-computer interaction.* Hillsdale, NJ: Erlbaum.
Nystrand, M. (Ed.). (1981). *What writers know: The language, process, and structure of written discourse.* New York: Academic Press.
Olson, D.R. (1977). From utterance to text: The bias of language in speech and writing. *Harvard Educational Review, 47,* 257–281.
Ong, W.J. (1982). *Orality and literacy: The technologizing of the word.* New York: Methuen.
Owens, P. (1984, April). Thinktank and Promptdoc. *Popular Computing,* 186–188.
Pea, R.D. (1982). What is planning development the development of? In D. Forbes & M.T. Greenberg (Eds.), *New directions for child development. No. 18: Children's planning strategies* (pp. 5–27). San Francisco: Jossey-Bass.
Pea, R.D. (1985, June). Integrating human and computer intelligence. In E.L. Klein (Ed.), *New directions for child development. No. 8: Children and computers* (pp. 75–96). San Francisco: Jossey-Bass.
Pea, R.D. (in press). Beyond amplification: Using the computer to reorganize mental functioning. *Educational Psychologist.*
Pea, R.D., & Hawkins, J. (in press). Children's planning processes in a chore-scheduling task. In S. Friedman, E. Scholnick, & R. Cocking (Eds.), *The growth of cognitive planning skills.* New York: Cambridge University Press.
Perl, S. (1979). The composing process of unskilled college writers. *Research in the Teaching of English, 13,* 317–336.
Plimpton, G. (Ed.). (1981). *Writers at work: The Paris Review interviews.* New York: Penguin.

Resnick, L.B. (1981). Instructional psychology. *Annual Review of Psychology, 32,* 659–704.
Resnick, L.B. (1985). *Education and learning to think.* Report prepared for the Commission on Behavioral and Social Sciences and Education. Washington, DC: National Academy Press.
Riel, M.M. (1983). Education and ecstasy: Computer chronicles of students writing together. *Quarterly Newsletter of Comparative Human Cognition, 5*(3), 59–67.
Riel, M.M. (1985). The Computer Chronicles Newswire: A functional learning environment for acquiring literacy skills. *Journal of Educational Computing Research, 1,* 317–337.
Rohman, G. (1965). Pre-writing: The stage of discovery in the writing process. *College Composition and Communication, 16,* 106–112.
Rubin, A. (1980). Making stories, making sense. *Language Arts, 57,* 285–298.
Rubin, A. (1983). The computer confronts language arts: Cans and should for education. In A.C. Wilkinson (Ed.), *Classroom computers and cognitive science* (pp. 201–217). New York: Academic Press.
Rubin, A.D., & Bruce, B.C. (in press). QUILL: Reading and writing with a microcomputer. In B.A. Hudson (Ed.), *Advances in reading and language research.* Greenwich, CT: JAI Press.
Scardamalia, M. (1981). How children cope with the cognitive demands of writing. In C.H. Frederiksen, M.F. Whiteman, & J.F. Dominic (Eds.), *Writing: The nature, development, and teaching of written communication* (pp. 81–103). Hillsdale, NJ: Erlbaum.
Scardamalia, M., & Bereiter, C. (1983a). Child as coinvestigator: Helping children gain insight into their own mental processes. In S.G. Paris, G.M. Olson, & H.W. Stevenson (Eds.), *Learning and motivation in the classroom* (pp. 61–82). Hillsdale, NJ: Erlbaum.
Scardamalia, M., & Bereiter, C. (1983b). The development of evaluative, diagnostic, and remedial capabilities in children's composing. In M. Martlew (Ed.), *The psychology of written language: A developmental approach.* London: Wiley.
Scardamalia, M., & Bereiter, C. (1985). Written composition. In M. Wittrock (Ed.), *Handbook of research on teaching* (3rd ed.). New York: Macmillan Education.
Scardamalia, M., & Bereiter, C. (in press). The development of dialectical processes in writing. In D. Olson, N. Torrance, & A. Hildyard (Eds.), *Literacy, language, and learning: The nature and consequences of reading and writing.* New York: Cambridge University Press.
Scardamalia, M., Bereiter, C., & Fillion, B. (1981). *Writing for results: A sourcebook of consequential composing activities.* La Salle, IL: Open Court.
Scardamalia, M., Bereiter, C., & Goelman, H. (1982). The role of production factors in writing ability. In M. Nystrand (Ed.), *What writers know: The language, process, and structure of written discourse* (pp. 173–210). New York: Academic Press.
Scardamalia, M., Bereiter, C., & Steinbach, R. (1984). Teachability of reflective processes in written composition. *Cognitive Science, 8,* 173–190.
Scardamalia, M., & Paris, P. (in press). The function of explicit discourse knowledge in the development of text representations and composing strategies. *Cognition and Instruction.*
Schank, R. (1982). *Dynamic memory.* New York: Cambridge University Press.
Schwartz, H.J. (1984). SEEN: A tutorial and user network for hypothesis testing. In W. Wresch (Ed.), *The computer in composition instruction: A writer's tool* (pp. 47–62). Urbana, IL: National Council of Teachers of English.

Scribner, S., & Cole, M. (1981). *The psychology of literacy.* Cambridge, MA: Harvard University Press.
Shaughnessy, M. (1977). *Errors and expectations.* New York: Oxford University Press.
Shuford, R.S. (1985, November). CD-ROMs and their kin. *Byte, 10*(12), 137–146.
Simon, H.A. (1981). *The sciences of the artificial* (2nd ed.). Cambridge, MA: MIT Press.
Simon, J. (1973). *La langue ecrite de l'enfant.* Paris: Presses Universitaires de France.
Sleeman, D., & Brown, J.S. (1982). *Intelligent tutoring systems.* New York: Academic Press.
Smith, F. (1982). *Writing and the writer.* New York: Holt, Rinehart & Winston.
Sommers, N.I. (1980). Revision strategies of student writers and experienced adult writers. *College Composition and Communication, 31,* 378–388.
Sprague, R.A. (Ed.). (1985, January). Third International Conference on Optical Mass Data Storage. *Proceedings of the Society of Photo-optical Instrumentation Engineers, 529.*
Tannen, D. (Ed.). (1982). *Spoken and written language: Exploring orality and literacy.* Norwood, NJ: Ablex.
Tetroe, J., Scardamalia, M., Bereiter, C., & Burtis, J. (in press). Goals in composition planning. In S. Friedman, E. Scholnick, & R. Cocking (Eds.), *The growth of cognitive planning skills.* New York: Cambridge University Press.
Tou, F.N., Williams, M.D., Fikes, R., Henderson, A., & Malone, T. (1982). RABBIT: An intelligent database assistant. *Proceedings of the American Association of Artificial Intelligence,* Philadelphia, PA: AAAI.
Van Lehn, K. (1985). *Theory reformulation caused by an argumentation tool.* Technical Report. Palo Alto, CA: Xerox Palo Alto Research Center.
Von Blum, R., & Cohen, M.E. (1984). WANDAH: Writing-Aid AND Author's Helper. In W. Wresch (Ed.), *The computer in composition instruction: A writer's tool* (pp. 154–173). Urbana, IL: National Council of Teachers of English.
Walberg, H.J., & Majoribanks, K. (1976). Family environments and cognitive development. *Review of Educational Research, 46,* 527–551.
Wason, P.C. (1980). Conformity and commitment in writing. *Visible Language, 14*(4), 351–363.
Wason, P.C. (1983). Trust in writing. In M. Wrolstad (Ed.), *Toward a new understanding of literacy.* New York: Plenum.
Weyer, S.A. (1982). The design of a dynamic book for information search. *International Journal of Man-Machine Studies, 17,* 87–107.
Wilkinson, A.C. (Ed.), (1983). *Classroom computers and cognitive science.* New York: Academic Press.
Wood, B.D., & Freeman, F.N. (1932). *An experimental study of the educational influences of the typewriter in the elementary school classroom.* New York: Macmillan.
Woodruff, E., Scardamalia, M., & Bereiter, C. (1982). Computers and the composing process: An examination of computer-writer interaction. In R. Shostak (Ed.), *Computers in composition instruction* (pp. 33–44). Eugene, OR: International Council for Computers in Education.
Woods, D.W. (1986). Cognitive technologies: The design of joint human-machine cognitive systems. *AI Magazine, 6,* 86–92.
Wresch, W. (Ed.), (1984a). *The computer in composition instruction: A writer's tool.* Urbana, IL: National Council of Teachers of English.

Wresch, W. (1984b). Questions, answers, and automated writing. In W. Wresch (Ed.), *The computer in composition instruction: A writer's tool* (pp. 143–153). Urbana, IL: National Council of Teachers of English.
Wright, P., & Lickorish, A. (1983). Proof-reading texts on screen and paper. *Behavior and Information Technology, 2,* 227–235.
Young, R.E. (1976). Invention: A topographical survey. In G. Tate (Ed.), *Teaching composition: Ten bibliographical essays.* Fort Worth: Texas Christian University Press.

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QUILL. D.C. Heath and Co., 125 Spring St., Lexington, MA 02173.
Random House Reference Set. Reference Software Inc., 2362 Boulevard Circle, Walnut Creek, CA 94595.
ReadySetGo. Manhattan Graphics Corp., 163 Varick St., New York, NY 10013.
Scripsit. Tandy/Radio Shack, One Tandy Center, Fort Worth, TX 76102.
SmartKey. Software Research Technologies, 3757 Wilshire Blvd., #211, Los Angeles, CA 90010.
Story Machine. Spinnaker Software/Designware, 215 First Street, Cambridge, MA 02142.
Story Maker. Bolt, Beranek & Newman, Inc., 10 Moulton St., Cambridge, MA 02238.
SuperKey. Borland International, 4585 Scotts Valley Dr., Scotts Valley, CA 95066.
SuperScripsit. Radio Shack, 300 One Tandy Center, Fort Worth, TX 76102.
Symphony. Lotus Development Corp., 161 First St., Cambridge, MA 02142.
TECO. Digital Equipment Corp., 200 Baker Ave., West Concord, MA 01742.
The Word Plus. Oasis Systems, 2765 Reynard Way, San Diego, CA 92103.
ThinkTank. Living VideoText, Inc., 2432 Charleston Rd., Mountain View, CA 94043.
Turbo Lightning. Borland International, 4585 Scotts Valley Dr., Scotts Valley, CA 95066.
UNIX. AT&T Bell Laboratories, 6 Corporate Place, Piscataway, NJ 08854.
VisiWord. VisiCorp, 2895 Zanker Rd., San Jose, CA 95134.
Word. Microsoft Corp., 10700 Northup Way, P.O. Box 97200, Bellevue, WA 98009.
WordPerfect. SSI Software, 288 West Center St., Orem, UT 84057.
WordStar. MicroPro, 33 San Pablo Ave., San Raphael, CA 94903.
Word Finder. Writing Consultants Inc., 300 Main St. East, Rochester, NY 14445.
The Word Plus. Oasis Systems, 2765 Reynard Way, San Diego, CA 92103.
Word Proof II. IBM Entry Systems Division, 5201 S. Congress Ave., Boca Raton, FL 33431.
WordStar. MicroPro International Corp., 33 San Palo Ave., San Rafael, CA 94903.
Writer's Helper. CONDUIT, University of Iowa-Oakdale Campus, Iowa City, IA 52242.
Writer's Workbench. AT&T Bell Laboratories, 6 Corporate Place, Piscataway, NJ 08854.
Writing Adventure. DLM. One DLM Park, Allen TX 75002.
XyWrite II-PLus. XyQuest, Inc., P.O. Box 372, Bedford, MA 01730.
ZyINDEX. ZyLAB Corp., 233 E. Erie St., Chicago, IL 60611.