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Reflections on Research on Writing and Technology for Struggling Writers

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In this article, I discuss research on the use of technology to support the writing of students with learning disabilities. Struggling writers can benefit from a wide range of computer applications for writing. Word processing, spelling checkers, word prediction, and speech recognition offer support for transcription and revision. Word processing also opens up opportunities for more meaningful publication of writing. Outlining programs and concept mapping software can help with planning. New forms of writing, including Internet chat, blogs, multimedia, and wikis, have not been studied extensively, but they may offer both opportunities and challenges to struggling writers. In addition to describing the research, I try to articulate some general themes and principles that I hope will be helpful to both teachers and researchers.

One of the challenges and fascinations of studying educational technology is the constant change in the nature of the subject caused by rapid advancement in hardware and software applications. Thus, I was intrigued when asked to write about my program of research on writing and technology taking a narrative perspective on the questions posed and solutions found. In my first study of word processing (MacArthur & Shneiderman, 1986), students used computers with dual floppy drives, one for the application and one for documents. In contrast, my latest article is about the educational potential of Web2.0 applications such as blogs and wikis (MacArthur & Karchmer-Klein, in press). In just 25 years, we have progressed from the first computers useful for word processing in schools to e-mail and Internet searches to Web2.0 applications that support easy creation of Internet content by users. As recognized in contemporary standards (e.g., National Council of Teachers of English & International Reading Association, 1996), students need to develop a range of new skills with technology to be considered fully literate. At the same time, many things remain the same. Although students need to master new skills, they also need to develop basic writing skills, learn to use language effectively, and read and write critically. The organization of schooling has not changed much, and teachers still struggle to integrate technology with education, or ignore it. Now, as then, many students know more about technology than their teachers. Now, as then, technology is a tool that can have positive or negative effects depending on how well instruction takes advantage of its capabilities.

In this article, I discuss research on the use of technology to support the writing of students with learning disabilities (LD) with a particular but not exclusive emphasis on research conducted by my colleagues and myself. Struggling writers can benefit from a wide range of computer applications for writing. Word processing, spelling checkers, word prediction, and speech recognition offer support for transcription and revision. Word processing also opens up opportunities for more meaningful publication of writing. Outlining programs and concept-mapping software can help with planning. New forms of writing, including Internet chat, blogs, multimedia, and wikis, have not been studied extensively, but they may offer both opportunities and challenges to struggling writers. In addition to describing the research, I try to articulate some general themes and principles that I hope will be helpful to both teachers and researchers.

In the first section of this article, I begin where my colleagues and I began, with research on word processing. The discussion emphasizes issues of integration with classroom writing instruction and opportunities to take advantage of its capabilities to support struggling writers. The second section focuses on assistive technology to help students compensate for problems with basic transcription and sentence generation, particularly word prediction and speech recognition. Key issues here are the software design, the match between tools and students' needs, and implementation in school settings. In the third section, I consider tools with potential to support planning and revising processes, particularly concept-mapping software and automated essay scoring systems, two applications I have recently begun to investigate. Finally, I consider new environments and forms for writing using multimedia and the Internet and their implications for struggling writers. Research in this area is extremely limited, but it is critical to teach our students to use online communication tools because of the increasing importance of the Internet in contemporary society.

Word Processing

As noted earlier, my first study of educational technology focused on the use of word processing with students with LD in a summer literacy program (MacArthur & Shneiderman, 1986). Students wrote articles and stories that we published in a camp newsletter, and we studied qualitatively the difficulties that students had in mastering this new tool and noted their enthusiasm for publishing. My interest in word

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processing was partly stimulated by my observation, later supported in a series of case studies of special education teachers using technology with my colleague David Malouf (MacArthur & Malouf, 1991), that word processing was a promising application because teachers could integrate it relatively easily with common process approaches to writing. At the time, classroom computer use was commonly categorized as computer-assisted instruction (CAI), programming instruction, or tool software, mostly word processing. Programming instruction, usually in Logo, was advocated by progressive, constructivist educators (Papert, 1980) but required a substantive revision in the goals of education and was uncommon in schools, particularly in special education. CAI was mostly drill and practice though there were a few creative simulations and discovery programs, like Oregon Trail or the Geometry Supposer. CAI had some instructional value with students with LD (MacArthur, Ferretti, Okolo, & Cavalier, 2001) but the software itself usually had few management features, and it created major management problems for teachers; evaluating software, matching content to individual students, scheduling computer time, and monitoring student work were all difficult. In contrast, word processing was technically simple and fit nicely with current conceptions of writing as a process involving recursive cycles of planning, drafting, and revising leading to publishing. Although there were problems of insufficient access to computers and weak typing skills, when teachers had access, they seemed able to use word processing in ways that supported their overall writing program.

One of the most obvious potential benefits of word processing is that the ease of editing might encourage more and better revision. Elementary and secondary students engage in relatively little substantive revision (Fitzgerald, 1987). In our own descriptive research with students with LD writing by hand (MacArthur, Graham, & Schwartz, 1991), we found not only that they made few substantive revisions, but also that they were equally likely to make changes that made their papers better or worse. Word processing seemed like a promising tool to enhance their revising. Daiute (1986) had reported preliminary evidence that students revised more when writing with a word processor. We conducted a study comparing handwriting and word processing with fifth-grade students with LD who had about a year's experience using word processing (MacArthur & Graham, 1987). We also included a dictation condition to represent students' performance without any barriers caused by text production. We found that simply providing access to word processing without instruction in revising had no effect on students' writing. Although dictated papers were longer and better, the handwritten and word-processed papers did not differ in length, syntactic complexity, vocabulary, errors of spelling and capitalization, or overall quality. In addition, there were no differences in overall amount or type of revision, although we did find a difference in the timing of revision: students made more revisions *during writing* with word processing but more revisions *between drafts* while handwriting. Later, as part of a study of a yearlong writing instruction program that included word processing (MacArthur, Graham, Schwartz, & Shafer, 1995, more information below), we compared handwriting and word processing on the posttest. Again, there were no differences in final drafts composed via handwriting and word processing. Our conclusion was that simple access to word processing for a particular piece of writing does not lead to more or different revision.

We subsequently turned our attention to the design of instruction in revising to use in combination with word processing. Our thinking was that word processing would support instruction in revising by eliminating recopying, which is not only tedious but also can result in new errors for students with LD, and by providing a neat copy for reading. The first of three studies evaluated a revising strategy for individual students (Graham & MacArthur, 1988). The other two studies investigated a peer-revising strategy in a multiple baseline design with a research assistant providing instruction (Stoddard & MacArthur, 1993) and in a quasi-experimental design in special education classrooms (MacArthur, Schwartz, & Graham, 1991a). The strategies all involved teaching students criteria for evaluating their writing (e.g., "Is there anything that is hard to understand?" or "Where could more information be added to make it more interesting?") and practice revising in response to the evaluations. Students wrote and revised all compositions on a word processor in both treatment and control conditions. Thus, the studies contrasted word processing with and without revising instruction. In all three studies, instruction had positive effects on the amount and quality of revisions, change in quality from first to final draft, and final quality. The results do not demonstrate that the word processor is essential to the success of the instruction, but my experience helping teachers teach revising strategies without word processing indicates that there is substantial student resistance to frequent revision when recopying is needed.

The results support a general principle that technological tools by themselves have little impact on learning, especially for struggling learners; rather, learning depends on a combination of the technology and instruction designed to help students take advantage of the capabilities of the technology. Pursuing this idea and reasoning that teachers would need support to design writing instruction that integrated word processing effectively, we implemented and evaluated a writing curriculum for students with LD. The Computers and Writing Instruction Project (MacArthur, Graham, & Schwartz, 1993; MacArthur, Schwartz, & Graham, 1991b; MacArthur et al., 1995) integrated three components: a process approach to writing implemented as writers' workshop, strategy instruction in planning and revising, and word processing. Students participated in a writers' workshop with typical features such as self-selected writing topics, daily sharing with the class, teacher conferencing, mini-lessons, peer-revising groups, and publication in a variety of forms.

In addition, students learned strategies for planning and revising following the self-regulated strategy development model (Graham & Harris, 2005). The peer-revising strategy was designed to fit the practice of peer revising in writers' workshop but with pairs instead of small groups and with more instruction, including extensive teacher modeling and guided practice in how to apply evaluation criteria and make revisions based on the evaluations. Students worked in pairs helping each other with their papers. As they learned to apply some criteria, new evaluation criteria were added to the strategy. The planning strategy involved the use of text structure

to generate and organize ideas. The strategy included three overall steps: (1) Think who I am writing for and why? (2) Plan using the text structure (represented as a mnemonic). (3) Write and say more. Students first learned to plan stories using the following text structure mnemonic: CSPACE for characters, setting, problem, actions, conclusion, and emotions. Later, they learned to generalize the strategy to persuasive essays with the mnemonic, TREE, for thesis, reasons, evidence, and ending. As they learned about these new types of writing, related evaluation questions were added to the revising strategy (e.g., "Are your characters described in interesting ways?"). Thus, the planning and revising strategies were integrated around writing genres.

Word processing was integrated with instruction in a comprehensive manner. Classes had sufficient access (about two students per computer) so that students could write their first drafts on the computer and return to revise them as often as needed. Students used typing instruction software to develop their skills with a goal of typing at a rate at least equal to typical handwriting speeds of about 15 words a minute. We observed that poor typing skills were a barrier to student writing, just as poor handwriting fluency interferes with writing. Some research indicates that typing speed is correlated with the quality of writing students produce on a word processor (Russell, 1999). When students met for peer revising, they printed extra copies of their papers for their editors to write on. Of course, students learned to use the spell checker. Finally, the word processor was used to produce a range of publications such as newsletters, collections of stories for the classroom, letters, and work for parents.

The CWIP experimental model was implemented in 12 elementary school self-contained classes for students with LD for a full school year (MacArthur et al., 1995). Students in the experimental classes made greater gains in the quality of their narrative and informative writing than students with LD in 10 control classes who received a process approach to writing without computers or strategy instruction. This study did not isolate the effects of word processing. However, it did demonstrate the effectiveness of a model of writing instruction that included word processing and strategies designed to take advantage of word processing capabilities.

One component of word processing that is especially important for students with LD is the spell checker. In one study, middle school students with LD who had moderate-to-severe spelling problems corrected 37 percent of their errors with a spelling checker, compared to 9 percent using a word processor and printout without a spell checker (MacArthur, Graham, Haynes, & De La Paz, 1996). We were more interested in exploring the limitations of spell checkers and how to work around them than in the entirely predictable finding that spell checkers are helpful for students with spelling problems, so we did a detailed analysis of errors. Correcting 37 percent of one's errors still leaves 63 percent uncorrected. The most serious limitation is that spell checkers fail to identify about one in three errors because the errors are some other word, either a homonym or a word with a close spelling (e.g., "wear" for "were" or "don" for "done"). Other research (Mitton, 1987) reported a similar finding that spell checkers miss about one-third of errors for typical high school students making spelling and typographic errors (e.g., my personal demon, "form" for "from"). Students need to understand how significant this problem is and proofread specifically to look for incorrect words. The second important limitation is that once an error is identified, the correct, intended word may not appear in the list of suggestions. This problem is especially likely for severely misspelled words (e.g., "frenichur" for "furniture" in one of our samples). Students need to learn to try alternate spellings if the intended word is not in the list. Most current spell checkers do a good job with phonetic spellings. A third potential problem is that students may not recognize the correct spelling in the list of suggestions; this problem did not occur often in our study (MacArthur et al., 1996), but the spell checker we used generally produced relatively short lists compared to current adult spell checkers. The solution is the same as for cases when the word does not appear—try an alternate spelling. A final limitation is that proper names or slang may be falsely identified as errors. In general, the students in our study recognized this issue, and it did not lead to many errors.

Some word processors have special features in their spelling checkers designed to help struggling writers deal with these problems. For example, the spell checker may identify homonyms and ask students to check them, or it may use speech synthesis to pronounce the words in the list of suggestions. These features may be important for some students with spelling and reading problems, though I am not aware of any research that has investigated such features. Most students work with standard word processors, so teachers need to help students learn to proofread for errors the spell checker did not find and use phonetic spellings when necessary to get more suggestions. McNaughton and his colleagues (McNaughton, Hughes, & Ofiesh, 1997), successfully taught high school students with LD to compensate for the limitations of spell checkers and correct far more of their errors.

Word processing is the one aspect of writing technology that is supported by a substantial research base. Meta-analyses of studies that compared writing instruction with and without word processing have found moderate positive effects on the quality of compositions with larger effects for low achieving students. The earliest meta-analysis (Bangert-Drowns, 1993) found a small effect size (ES) for quality (.27) across studies with elementary, secondary, and college students. This small ES is better viewed as a moderate ES (.49) for nine studies of remedial instruction for struggling writers and a near-zero ES (.06) for 11 studies with average writers. A more recent review (Goldberg, Russell, & Cook, 2003) found a somewhat larger ES for quality (.41). A recent meta-analysis of 19 studies, including some of those reviewed in the earlier analyses, limited to Grades 4 to 12 (Graham & Perin, 2007) found an ES of .51 for writers in general but a larger ES of .70 for low achieving writers (overall ES = .55). Although none of the studies provided specific results for students with LD, solid evidence indicates that using word processing in instruction has positive effects, especially for low achieving students.

To summarize this section, I offer my recommendations for effective use of word processing in writing instruction. The most fundamental requirement is a well-designed writing instruction program that includes frequent writing on

topics that are meaningful to students, opportunities to share their writing and get response from peers, teachers, and outside readers, instruction in planning and revising strategies, and instruction in basic skills. Within this context, I consider the following elements important. First, students need to learn to type at least as fluently as they handwrite. The fact that students may use technology regularly outside of school does not mean that they can type fluently. Typing instruction software seems to be an effective means to encourage students to use correct fingering and monitor their speed and accuracy. Of course, regular writing will help to provide practice. Second, to get the full benefit of word processing, students should complete the entire writing process from drafting through publication on the computer. Typing from a handwritten draft is a tedious and error-prone process, especially for students with poor spelling skills. Regular access to computers is a problem in many schools. Practical solutions include computer labs dedicated to word processing or inexpensive laptops designed just for writing (e.g., Alphasmarts). Third, students need to learn revising strategies in order to take advantage of the editing capabilities of word processing. They need to learn strategies for substantive revision as well as strategies for using spell checkers for editing. The same principle applies to planning strategies and software to support planning, which I discuss later in this article. Finally, teachers should take advantage of word processing to publish student writing in a variety of formats. In the real world, people write for others to read, and publishing is one of the primary motivations for writing.

Assistive Technology—Support for Transcription

Although a word processor with a spell checker is a powerful tool, some students with LD can benefit from additional support in producing text accurately and fluently. Consider, for example, the 10-year-old boy from one of our studies of word prediction who wrote the following entry in his dialogue journal: "The Redr was my farvt croms past. It a ras car Im go to red the sooc old tree to the little kers. good bay" [The red Rocket was my favorite Christmas present. It's a race car. I'm going to read *The Spooky Old Tree* to the little kids. Good bye.] This student's spelling problems were so severe that he always had to read his journal entries to the teacher, and do so immediately because he wouldn't be able to read them later. He also had trouble reading the teacher's responses. A spell checker would have been of little help.

A number of technological tools beyond word processing and spell checking have promise as assistive technologies to help students with LD compensate for difficulties with transcription, that is, with all the skills involved in getting text onto paper—spelling, handwriting, and conventions like punctuation and capitalization.

Word Prediction

In exploring solutions for students with severe spelling problems, I conducted a pair of studies of word prediction software (MacArthur, 1998, 1999). Word prediction was originally designed for individuals with physical disabilities to minimize the number of keystrokes needed to write. The software "predicts" the intended word from the initial letters and, in more sophisticated software, from grammatical cues and recently used words as well. For example, if the student above typed, "It was my f," the program would present a list of predicted words beginning with "f," such as "friend," "favorite," and "food." If he continued and typed "a," it would update the list to words that begin with "fa." The student could then select a word from the list by typing its number or clicking on it. Usually the software includes speech synthesis to read the words in the list.

Both studies used single-subject designs to test the effects of word prediction with 9–10-year-old students with LD who misspelled from 20 percent to 55 percent of their words. In both studies, students wrote in dialogue journals back and forth to their teachers. The first study (MacArthur, 1998) used a multiple-baseline design with reversal comparing word processing to word prediction. Students used simple word prediction software that used only spelling information for prediction and that provided speech synthesis for word lists and the completed text. The second study (MacArthur, 1999) used an alternating treatment design with handwriting, word processing, and word prediction conditions. It also used more complex word prediction software that used syntax and individual histories of word use to make predictions, and that included speech synthesis. Overall, six of the eight students in the two studies made dramatic gains in the readability and spelling of their writing. During baseline, their writing ranged from 55 percent to 85 percent legible words (i.e., readable in isolation) and 42 to 75 percent correctly spelled words. With word prediction, all six students increased their percentage of both legible and correctly spelled words to above 90 percent. To illustrate, the same student mentioned above wrote the following entry in response to his teacher's question about sharks: "my favorite is the great wit shark. what is your favorite."

This research shows the potential of word prediction software, but many questions remain. The effects of word prediction, like all assistive technology tools, depend on many factors such as the abilities and motivation of the students, the demands of the writing tasks, the details of software design, and instruction. My research on word prediction focused on students with severe spelling problems, but I have talked with many teachers who reported success using word prediction with students with less severe spelling problems, claiming that it increased motivation and helped them use more varied vocabulary. Further research on using word prediction for these purposes is much needed.

Software design is also important, as is the match among software design, student capability, and the demands of writing tasks. In observing students working with two different word prediction programs, I noticed that design features of the software had a significant impact on success. For example, the size of the dictionary affected how many letters needed to be typed before the intended word appeared in the list. In my second study, the larger dictionary made it more difficult for students to find the word they needed. When writing simple journal entries, they did not need this large

dictionary. However, when we increased the difficulty of the writing assignments, the word prediction showed a strong positive effect on their writing. Thus, it is important to match dictionary size to the type of writing the student needs to complete. One important solution is to permit users, or their teachers, to adjust the dictionary size and to add the special vocabulary they need. For example, if students are writing about a science, they can use a small general dictionary plus a dictionary of words related to the science topic. In this way, word prediction may help students learn to use specific vocabulary. Another software design problem is presented by spelling errors in the beginning of words, for example, starting "bread" with "ber." Some software now incorporates common spelling errors in generating suggestions, much like a spell checker. Software has improved since I conducted my studies, and the best programs permit the user to adjust the dictionary size, add vocabulary, and accommodate common spelling errors.

Speech Recognition

Speech recognition in its ideal form would be the ultimate assistive technology for writers who struggle with transcription. It would permit writers to compose by dictating, yet unlike dictating to a tape recorder, it also would permit them to see the emerging text and reread as needed. Of course, the technology has still not reached this ideal state. The systems continue to make recognition errors although they have improved dramatically in the past 20 years. I had been interested in speech recognition for some time, but I didn't think it was practical as a composing tool until *continuous* speech recognition became available in the late 1990s. Prior to that time, *discrete* speech recognition required users to dictate a word at a time and check the accuracy of each word while writing. Higgins and Raskind (1995) had studied the use of discrete speech recognition for composing by college students with LD and found that it enhanced the quality of writing compared to handwriting. However, for elementary and high school students, it seemed to me that the cognitive burden was too great to be worthwhile. But continuous speech recognition permitted the user to speak in full sentences and even paragraphs, though it still required dictation of punctuation. When Dragon Naturally Speaking (1998) was introduced with continuous speech recognition, my colleagues and I decided to investigate its use with students with LD.

The potential value of speech recognition is supported by research showing that students with LD and other struggling writers can generally produce longer and higher quality papers by dictating than by handwriting or word processing (Graham, 1990; MacArthur & Graham, 1987; Reece & Cummings, 1996). Speech recognition has one advantage over normal dictation to a tape recorder; namely that the writer can see and reread the emerging text during writing. In a particularly interesting series of studies, Reece and Cummings (1996) compared handwriting to two forms of dictating—dictating to a tape recorder and dictating to a simulated speech recognition system, actually a hidden typist, which permitted writers to see the emerging text. Normally achieving students wrote better papers in the simulated speech recognition condition than in dictation to a tape recorder, showing the importance of being able to see the existing text. However, struggling writers produced better texts in both dictation conditions than with handwriting, showing the importance for them of removing the difficulties caused by transcription.

Our initial attempts to use continuous speech recognition with fifth- and eighth-grade students with LD were not successful because the systems were unable to recognize their nonadult voices. However, Dragon soon produced a version that included voice patterns for younger students and our pilot results with eighth- and 10th-grade students were encouraging, so we designed a study with 10th-grade students (MacArthur & Cavalier, 2004). The study was designed, first, to answer questions about the feasibility of speech recognition for composing. We wanted to find out simply whether students could use it to compose with acceptable accuracy and without undue frustration. In addition, we planned to test the validity of using it as a test accommodation for students with LD. Thus, we included both students with and without LD, hoping to show that speech recognition would improve the performance of the students with LD but have little effect for non-LD students who had little difficulty with transcription. All students wrote persuasive essays in three conditions: handwriting, speech recognition, and dictation to a scribe who typed so that writers could see the emerging text.

Speech recognition presents a number of challenges to users. First, the accuracy of the software is an issue. Software reviews typically report accuracy for adults of 95 percent or better (e.g., Metz, 2006). Second, students must learn to speak clearly, to avoid intrusions like "um," and to dictate punctuation. Third, they need to learn new editing skills. The software never makes spelling mistakes; instead students need to edit for incorrect words. Most speech recognition software supports this kind of editing by reading back the writer's voice while highlighting words. We designed a training routine that addressed these issues. In addition, we taught students a basic procedure for planning a persuasive essay using a graphic organizer. Students participated in 6 hours of individual training and practice.

Excluding one student who dropped out of the study, all 31 students were able to use the speech recognition with acceptable accuracy. The students achieved 87 percent accuracy on average on a sentence dictation task without editing, and 92 percent accuracy on their essays with editing. Most errors were minor, such as word endings and small words like articles and prepositions that are not articulated clearly. The students with LD made fewer errors using speech recognition than handwriting. Most important, students with LD produced higher quality essays using speech recognition than handwriting. In addition, they produced the best essays in the ideal condition of dictating to a scribe when they did not have to worry about transcription at all. No statistically significant differences among conditions were found for students without LD. We concluded that high school students with LD could learn to use speech recognition to compose with a reasonable amount of practice. Further, we interpreted the results to support the use of dictation as a test accommodation; it improved the performance of students with LD by

removing transcription barriers to their composing but did not affect the performance of students without disabilities.

Quinlan (2004) reported similar results with middle school students with and without problems in writing fluency. After 3 hours of training, students wrote papers using handwriting and speech recognition. Students with writing problems, but not the average writers, wrote longer papers and made fewer errors using speech recognition.

The use of speech recognition is not limited to struggling writers. Software development was driven by an expectation that professionals would find it to be an easier way to compose. Some investigators are studying its use by professionals (e.g., Leijten, 2007). I personally find it helpful for certain tasks where rapid text production is helpful. For example, when transcribing interviews from tape using speech recognition, I can almost keep up with the tape instead of constantly rewinding.

Despite the substantial potential of speech recognition for struggling writers, there are many practical challenges. It is impractical for use in school classrooms because the software requires a relatively quiet environment for accuracy and because dictation is too public a process. It is more realistic to consider its use in a resource room setting or at home. College students with LD might benefit especially from speech recognition because they face demands for substantial amounts of writing. Engstrom (2005) reported on successful use of speech recognition along with assistive technology for reading with a population of college students with LD. More longitudinal studies of use that address practical issues and student motivation are much needed. Longer studies could investigate the factors that influence whether students continue to use speech recognition or not. They could also investigate experienced, proficient users to understand how they adapt to the limitations of speech recognition, how they perceive its benefits and challenges, and how much fluency they develop in its use.

Support for Planning and Revising

Since the early days of word processing, developers and researchers have explored ways to use technology to support writers in planning and revising, including software that prompts writers with general questions about goals and content or about evaluation criteria, software for outlining or concept mapping, and programs that automatically evaluate essays and provide feedback (for a review, see MacArthur, 2006). The theoretical rationale for such planning support makes sense, especially for struggling writers. Research without computers has shown that prompts to set goals during planning and revising (Ferretti & MacArthur, 2001; Graham, MacArthur, & Schwartz, 1995) and prompts to generate content based on text structure (Montague, Graves, & Leavell, 1991) can enhance the writing of students with LD. Outlining and graphic organizers or concept maps are widely used in writing instruction, and graphic organizers based on text structure are an important component of cognitive strategies for planning that have proven value with students with LD (Graham, 2006).

Concept Mapping

Most word processors include support for outlining, and one program for electronic concept mapping, Inspiration (2009), is quite common in schools. Electronic concept maps and outlines have some advantages over paper and pencil versions. One advantage is the ease of revision; new ideas can be inserted and the organization of information can be easily changed. Electronic concept maps can be expanded beyond the reasonable limits of paper ones, and the details can be hidden to reveal the organization of main topics. In addition, electronic maps can be automatically converted into outlines. Thus, ideas can be generated in a visual format that highlights connections among them. Then, converting the map to an outline can help in designing the linear organization needed for writing.

Some work on technology support for planning has focused on students with LD. The most extensive work has been by Anderson-Inman and her colleagues (e.g., Anderson-Inman & Horney, 1998), who have conducted a number of qualitative studies of concept mapping as a tool to support reading and studying by students with LD. They have reported on processes for using concept mapping to take notes from textbook reading, and then using those notes to study and write content-area papers. One quasi-experimental study (Sturm & Rankin-Erickson, 2002) compared the effects of paper-and-pencil and electronic concept mapping on the writing of middle school students with LD. After receiving instruction in both mapping by hand and mapping on the computer, students wrote essays with no mapping, hand mapping, and computer mapping. No significant differences in the length or quality of essays were found among the three conditions, although both length and quality increased from pretest to posttest. Englert and her colleagues (Englert, Wu, & Zhao, 2005; Englert, Zhao, Dunsmore, Collings, & Wolbers, 2007) investigated a web-based program to support writing by elementary students with LD. The online system provided a planning graphic organizer for informative writing with topic headings provided by the teacher; it also provided a drafting template with boxes for the introduction and conclusion and for topic, supporting, and concluding sentences for body paragraphs. In one study (Englert et al., 2007), they compared this online support with paper-and-pencil organizers using the same structures. Papers written with the online support were longer, better organized, contained more relevant content, and were higher in overall quality than papers written using the printed organizers and handwriting.

My colleagues and I recently completed a study of an instructional method for using concept-mapping software to support writing (Karchmer-Klein, MacArthur, & Najera, 2008). The study used Inspiration software and focused on compare-contrast writing. Instruction included several components. First, students used a template representing the text structure of compare-contrast writing that asked students to generate categories for comparison. Second, once students had generated the concept-map, they converted it into an outline form. In the outline form, they reorganized the ideas and wrote complete sentences. We thought that writing the full sentences in the outline form would provide support in

creating good topic and supporting sentences. Third, students exported the outlines to a word processor, where they made final revisions to format the paragraphs correctly, add needed transitions, and improve the paper in general. Fourth, the entire process was modeled and explained by the teacher. The teacher explained the purposes and organization of compare-contrast writing, and demonstrated all the steps of planning and writing a paper, using think aloud modeling. Students then practiced using the software with guidance. Instruction was limited to four sessions because our primary focus was on evaluating the impact of using the concept-mapping software.

Students were randomly assigned to three conditions: concept mapping with transfer to outline as described above, concept mapping without the outline, and word processing with brainstorming as a planning method. Students in both concept-mapping groups outperformed the control group on the measure of compare-contrast text structure. However, differences in overall quality were not significant. The study demonstrates the potential of concept mapping with only a modest amount of instruction. From my perspective, the key issues in studying the use of technology to support writing are about instructional design. For example, for this study, how should the template be designed? Is it helpful for students to use the outlining feature as extensively as we planned? How could the instruction be integrated with reading for information, which seems like an important aspect of compare-contrast writing? Thus, I think of this study as one in a series of design studies.

Automated Essay Scoring Systems

Automated essay scoring (AES) systems have been developed that have the capability to evaluate the quality and content of written essays. Research has demonstrated that AES systems can evaluate the overall quality of essays with adequate interrater reliability with humans. In general, studies have shown that correlations between human raters and AES are as large as correlations among human raters (Shermis, Burstein, & Leacock, 2006). In addition, systems based on latent semantic analysis are able to evaluate the semantic content of writing and how well it matches criterion texts (Landauer & Psotka, 2000).

In addition to its use in large-scale writing assessment, AES has potential as a tool to support instruction. Evaluating and commenting on essays is a labor-intensive task for teachers, which limits both the amount of feedback that teachers can provide students and the immediacy of that feedback. AES systems can provide feedback to students on their writing in iterative cycles of revision and evaluation with little to no delay. A number of AES systems are now commercially available that evaluate student essays and provide feedback and suggestions for improvement.

One such system, Summary Street (Wade-Stein & Kintsch, 2004), is based on latent semantic analysis, which evaluates the content of writing and how well it matches criterion texts. Summary Street evaluates summaries written by students and provides feedback on how well the summaries cover the content of a text, whether they meet length requirements, and which sentences might be redundant or irrelevant. The developers of the system have conducted three studies with sixth- and eighth-grade students (Franzke, Kintsch, Caccamise, Johnson, & Dooley, 2005; Steinhart, 2001; Wade-Stein & Kintsch, 2004). Summary Street was compared to writing summaries on a word processor that only gave feedback on length and spelling. In all three studies, summaries written with feedback from Summary Street were higher in quality and content coverage than those written without this feedback. These findings are quite promising, but research on these tools is still at the beginning stages.

Initial studies of the use of such AES systems in schools have found relatively limited use by teachers. For example, Grimes and Warschauer (2006) examined how teachers and students made use of the automated feedback in two programs *MY Access!* and *Intellimetric*. Although teachers had positive opinions of the software, they did not use it often, and students generally did not use it to make revisions. As with most instructional technology, the effects of AES systems on learning depend on how the technology is integrated with instruction. At this point, little is known about effective ways to make use of AES systems in instruction and about the opportunities and challenges such systems afford.

Consequently, one of my students and I (Moore & MacArthur, 2008) conducted a qualitative case study of two classrooms using AES systems, a regular education fifth-grade class and a middle school class in a private school for students with learning problems. Using think-aloud protocols of students using the system, interviews with teachers and students, and observation of classroom instruction, we tried to understand how students interpreted the evaluative ratings and feedback from the system and how their interpretations were influenced by the instruction they received in the classroom. In general, we found that students were motivated by the scores to revise their papers but that their understanding of the feedback and their revisions were limited primarily to evaluation criteria and revising techniques they had learned from their teachers.

AES systems have considerable promise in the writing classroom. More research on instructional applications is needed. In addition, AES might be useful in the development of sensitive measures for monitoring writing progress. However, research has not yet explored their validity for this purpose.

New Environments and Forms of Writing

In this article so far, I have written about the use of technology to support the development of traditional writing skills and the production of written documents. However, technology is having and will have a broader impact on literacy through the development of new environments for writing and forms of written communication. According to a recent survey by the Pew Internet and American Life Project (Lenhart, Arafeh, Smith, & MacGill, 2008), 85 percent of teens ages 12–17 engage at least occasionally in some form of electronic personal communication including text and/or instant messaging, e-mailing, social networking, or blogging. Daily, 36 percent of teens send text messages; 29 percent use instant

messaging; 23 percent communicate via a social network site (SNS); and 16 percent send e-mail. Readership for newspapers and novels has trended down for many years as more people get their news and entertainment online. The most recent presidential election highlighted the importance of Internet communication for participation in public affairs.

Previous technologies also had dramatic effects on how people received information and communicated, and educators have long debated the influence of television and other technologies on literacy learning. The Internet differs from previous print and electronic forms of communication in several ways that present both opportunities and challenges for schooling (MacArthur & Karchmer-Klein, in press; Reinking, McKenna, Labbo, & Kieffer, 1998). First, digital texts on the Internet integrate text and audiovisual media, changing the process of reading and writing in important ways. The inclusion of audiovisual features offers another channel for acquiring information for students who struggle with reading, but it may also encourage overreliance on nonverbal information, as critics have charged for television. Second, information is presented in a nonlinear, interlinked web that requires readers to make choices about what to read and requires writers to anticipate the choices readers will make. Third, the sheer amount of information available on the Internet affects the skills needed for literacy, emphasizing skill in searching for and critically evaluating information. The links among information are essential to the nature of the web and the vast information available, but searching for and reading information on the Internet requires new skills that may be difficult for weak readers. For example, defining search terms requires vocabulary knowledge as well as content knowledge. Skimming large amounts of information demands reading fluency. Finally, the Internet is a highly interactive technology that encourages users to create and share content as writers. E-mail and later chat applications made it easy to communicate with known friends. The second generation of Internet tools, often referred to as Web2.0, has added blogs, wikis, social networking sites, and video-sharing sites like YouTube, that expand the options for users to write on the Internet. These tools provide access to a wide range of audiences and make it easy for the audience to write back. Writing to authentic audiences may motivate students to write and provide useful responses to their writing or opportunities to collaborate. On the other hand, these tools also create security and privacy concerns. In addition, the informal writing often done on the Internet may not help students develop the skills they need.

As educators, we need to be concerned about two types of outcomes. First, we need to consider how to use technological tools to help our students develop effective writing skills in general. Second, we need to recognize that students need to learn how to access information and communicate effectively in the new environment of the Internet. Skill in the use of these tools is important for future employment, for participation as a citizen, and for personal purposes. In pursuing both purposes, we need to be critical about the effects of new technologies. The effects of technology on learning always depend on the particular activities and instruction that teachers design.

Despite widespread access to the Internet and theories about its effects on literacy activities, there is limited research on its impact on literacy, especially on writing and writing processes, and even less research on students with LD. In this section, I will briefly discuss a few studies on two new technologies for writing: composing hypermedia and written communication via the Internet.

Composing Hypermedia

Like hypertext, hypermedia includes numerous links among separate sections or pages of content, thus breaking up the linear structure of traditional printed text. In addition, it includes multiple media. Much of the content on the Internet would be considered hypermedia. Although a considerable amount of research has investigated the design of hypermedia for content learning (for a review, see Nesbit & Adesope, 2006), little work has addressed issues about learning to compose hypermedia. Research on composing hypermedia in schools consists mostly of qualitative case studies of classrooms where students work collaboratively on inquiry projects resulting in hypermedia documents. Erickson and Lehrer (1998), working with middle school social studies classes, documented the development of cognitive design skills, including research skills, planning and management, audience consideration, organization, presentation, and evaluation. Over time students moved from attention to superficial aspects of display and content links to a more rhetorical focus on designing links to communicate effectively with readers. Baker (2001) studied a fourth-grade class working on collaborative multimedia projects in science and social studies. She also documented the cognitive processes involved in composing finding many similarities with print composing. The visible nature of hypermedia projects supported high levels of peer interaction, but it also led some students to concentrate too much on display and presentation rather than content.

Students with LD were the primary focus of research with my colleagues Ralph Ferretti & Cindy Okolo (Ferretti & Okolo, 1996; Ferretti, MacArthur, & Okolo, 2001) on multimedia social studies projects in inclusive classrooms. We argued that multimedia projects are especially appropriate for students with LD because they offer multiple ways for students to learn and demonstrate their knowledge rather than relying entirely on reading and writing. Across two studies, we found that students with LD learned as much historical content as their nondisabled peers and that students' attitudes toward social studies increased. We also reported numerous challenges in implementation. The need to provide training in technology and the generally poor typing skills of the students created time-consuming bottlenecks. More substantively, analysis of group interaction revealed that some groups worked well together while in other groups the higher achieving students took over the project and essentially excluded the students with LD. The technical problems highlight the need for providing basic training in technology skills. In addition, teachers need to plan collaborative work carefully to ensure participation of all students.

Internet Communication

Much of what we know about the use of the Internet for writing projects comes from qualitative studies of innovative teachers. For example, Karchmer (2001) studied 13 teachers in Grades K to 12 who made extensive use of the Internet. The elementary teachers made a practice of publishing their students' writing on class web pages, in collaborative projects with other schools, or at online writing sites. They reported that students were highly motivated by having a wider audience. The secondary teachers used the Internet more for access to information than for publication of student work.

One growing use of the Internet is for intercultural communication projects, in which classes from different parts of the country, or world, collaborate on curriculum projects that involve shared inquiry and writing. In addition to developing cultural awareness and increasing targeted content knowledge, such projects may improve students' writing skills by enhancing motivation and by requiring them to write clearly to communicate with students who have different backgrounds and experiences. Garner and Gillingham (1996) conducted case studies of six teachers who used the Internet for intercultural communication projects. They found that teachers changed their teaching methods to devote more effort to inquiry projects that drew on student interests and authentic problems. They also found that the projects stimulated motivation for writing and encouraged children to attempt to understand cultural differences and consider audience needs.

An early project (Riel, 1985) illustrates the critical importance of the design on instructional activities in communication projects. The project, which involved communication between classrooms in California and Alaska, began with pen pal exchanges. But the developers and teachers soon realized that these exchanges were not contributing to writing skills because they were too informal to require evaluation and revision. Instead they redesigned the project as a newswire. Students posted articles online, and editorial boards (with rotating membership) in each classroom selected articles for their local edition of a newspaper, requesting revision as needed from the authors. This format involved students collaboratively in evaluation and provided responses and a reason for revision to writers. The intercultural aspect was important because writers had to consider what aspects of their articles would need explanation for an unfamiliar audience, and they received feedback when their writing was not clear. The project illustrates the principle that the design of writing activities and instruction is a critical ingredient in successful use of Internet communication.

Although I am not aware of any research on Internet communication specifically with students with LD, and I have not yet conducted such research myself, I think that the idea has potential for struggling writers. Writing for authentic audiences who respond to one's writing might motivate students to write more extensively and revise more carefully. In addition to considering the potential of Internet applications to improve students' writing skills, we need to recognize that learning to use these tools effectively is an important goal in its own right, based on their importance for communication in the contemporary world.

Concluding Comments

In concluding, I would like summarize a few important points for practitioners and researchers. First, the one area where there is sufficient research to draw fairly confident conclusions is word processing. The use of word processing in writing instruction has a moderate positive effect on student writing, especially for struggling writers. The key issues in successful use of word processing are access and integration with instruction. Schools need to provide adequate access to computers for students to complete both initial drafts and revisions with word processing. The effectiveness of word processing depends on adequate typing skills, so students should receive typing instruction and practice, probably beginning fairly early in elementary school. Teaching typing makes sense because it is the requirement for access to most technology tools. Word processing should be available as a test accommodation for students with disabilities. Furthermore, given the common access to word processing in work and other areas outside of school, it makes sense to permit students to use spell checkers on writing assessments, as well. In fact, the new National Assessment of Educational Progress writing assessment planned for 2011 will require all eighth- and 10th-grade students to write using word processing (National Council for Teachers of English, 2007). The principle of integration with instruction applies to all technology applications and includes the idea of designing instruction that teaches students to take full advantage of the technology. To take full advantage of word processing, students need to learn to evaluate their writing and revise effectively, and they need to learn to publish in a variety of formats.

Second, although the research on assistive technology for writing is limited, sufficient research exists to establish that applications like word prediction and speech recognition can be beneficial at least for some students. What we do not know enough about is who can benefit in what contexts. Is word prediction only helpful for students with severe spelling problems or could it also be helpful for reluctant writers or those who have trouble learning to type, or could it help all students use more varied vocabulary? Is speech recognition helpful to most adolescents with LD or only to those with the right combination of motivation and demanding writing tasks so that the extra efficiency matters? Can younger students learn to use speech recognition, and how do attention problems affect successful use? How can these tools be integrated into the home and school lives of students? Case studies would be very helpful in answering these questions, so I would encourage professionals who work with these tools to consider publishing case studies of successful and unsuccessful attempts to use assistive technology. In the meantime, we must rely on trials of technology with individuals to see which tools fit their skills and the demands they face for writing.

Third, we need more design studies in which researchers and teachers collaborate in cycles of developing, implementing, assessing, and revising instructional methods for using technologies for literacy. It is surprising how little research has been done on relatively common applications like concept mapping. New applications, such as using automated essay scoring software to provide feedback to students, will

need close collaboration between the technology developers and practitioners to figure out how to integrate the technology with instruction. For most writing technologies, the main question is not whether they work but how to design effective instruction using the technology.

Finally, I would like to reemphasize the importance of educators engaging with new environments and forms of reading and writing on the Internet. We need to evaluate these new communication technologies critically but proactively. First, I think teachers can find ways to use the opportunities offered by the Internet to improve students' writing skills, that is, their ability to communicate clearly for a variety of audiences and purposes. Second, regardless of the effect of the Internet on traditional writing skills, I think we need to help our students learn to communicate effectively using Internet applications. It is difficult to predict what reading and writing skills will be needed in the future, but it already seems clear that skills such as searching for information online, reading that information critically, integrating multimedia in writing, networking online, and writing online will be important skills. As educators, we need to understand how our students use technology and design ways to use those technologies in informed ways to help our students develop.

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