A Review of Technology-Based Approaches for Reading Instruction:
Tools for Researchers and Vendors

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Introduction

The ability to read is the main foundational skill for all school-based learning. Without it, the chances for academic and occupational success are limited (Lyon, 1997). In fact, the most pressing issue in guaranteeing students equal access to the curriculum is ensuring their ability to read class materials. When children do not learn to read, their general knowledge and writing abilities suffer. Given reading's fundamental role in learning, the National Center for Technology Innovation (NCTI) has identified current technology-based approaches that help students with reading disabilities (RDs) develop abilities to read and comprehend text.

In this paper, NCTI focuses primarily on computer-based technologies, software programs, and portable computerized devices that support reading outcomes. Because these technologies are increasingly complex and interrelated, we have adopted the terms assistive technology (AT) and accessible mainstream technology (AMT) to describe the broad range of mainstream and specialized software, hardware, and Internet-based programs and functions that can be used to support reading development. We do not mean to diminish the impact of adaptive strategies or low-tech assistive devices such as book holders, highlighting tape, and reading ruler guides. These frequently used items are valuable approaches for improving access to reading print-based books. However, with the increased use of computers in general education classrooms (National Center for Educational Statistics, 2004) and the increased availability of instructional materials in digital formats, computer-based approaches have become more flexible and therefore are able to address more learning needs of students with RDs.

Although AT and AMT approaches in general have the potential to create successful reading experiences for students, it is only when they are combined with effective teaching strategies that success occurs. Combining computer-based technologies with sound principles of

literacy instruction can help students develop the skills and confidence they need to be successful readers (Carnine & Kinder, 1985; Woodward et al., 1986). According to Dalton and Hannafin (1988), the highest achievement by students occurs when both traditional and technology-based approaches are used in ways that complement each other. With increasing numbers of mainstream students with disabilities (U.S. Department of Education, 2002) and increasing numbers of computers in general education classrooms (National Center for Educational Statistics, 2000), technological solutions are available that can complement effective teaching strategies and respond to the individual needs of poor readers.

This paper examines the potential of technology-based approaches for K–12 students with RDs. Although the existence of technological approaches is well documented in the general education classroom, the pace of technological innovation far exceeds the pace of research and publishing. The availability of products developed to meet the special needs of students with disabilities has increased steadily. With an expanding pool of technological choices, the efficacy of these approaches has not been validated to determine which intervention is most effective for which students in which situations. The purpose of this report is to explore available technologies that can be used to enhance the reading performance of students with RDs and to suggest gaps in research activities and improvements of product features.

In annual reviews of publications on the use of AT by students with disabilities, Edyburn (2000, 2001, 2002) found that the ratio of research to practice studies is slowly increasing. Clearly, there is more to be done. In reviewing research articles, syntheses, and reports (Edyburn, 2003a; Lewis & Doorlag, 1999; Lindsey, 1993; MacArthur, Ferretti, Okolo, & Cavalier, 2001; Maccini, Gagnon, & Hughes, 2002), we found the following:

- There is a small yet growing body of evidence indicating that technological applications can be effective in addressing some learning needs of students with disabilities. However, the samples in these studies are small.

- Much of what is being presented is believed, felt, or hoped. The empirical evidence is not sufficient.

- There are reports of success with individual students when technological supports are provided. Little is known about AT outcomes and their widespread, long-term impact.

- Technologies are being introduced and adopted by students and practitioners ahead of research. Many features simply have no research base.

What Is a Reading Disability?

RDs are significant deficits in reading that occur despite normal sensory abilities and educational opportunities and are not primarily caused by deficits in emotional or sensory abilities. RDs can manifest as a result of cognitive-linguistic deficits and acute disadvantages (Torgesen et al., 1999). RDs are one of the leading reasons for referral to special education services and the largest service area for students with learning disabilities (Edyburn, 2003d). With appropriate instruction and technology-based supports, students with RDs can and do make significant gains in reading achievement.

If we are to better understand how the design and use of technology can address the needs of students with RDs, we must first understand the barriers. According to LD Online (http://www.ldonline.org), individuals with RDs may experience one or more of the following barriers to reading fluently and with comprehension:

- Reads slowly and deliberately

- Rereads lines in oral reading

- May substitute, omit, or transpose letters, words, syllables, and phrases

- Has trouble using basic phonics to sound out words

- Has decoding problems (difficulty with sound-symbol relationships and distinguishing between sounds and between certain letters)

- Loses place on page or skips lines, words, and numbers

- Has poor comprehension of written materials

- Reads with an overdependence on guessing and thus compromises comprehension

- Does not like to read

Technology-Based Learning Environments

Computer technologies may provide improved learning environments for many students. Much of the early research cited below documents the changes in classrooms and teacher and student habits that were generated by the introduction of computers into learning environments. AT and AMT have advanced exponentially in the past two decades, yet it is instructive to remind ourselves of the impact that they have engendered. Presented below are specific features and observed outcomes that support the use of technology as a positive learning for students with disabilities. Computer learning environments can offer learning experiences that do the following:

- Motivate students by providing educational experiences that are at the student's present level of functioning (Lindsey, 1993) and by providing a context for the learner that is challenging and stimulates curiosity (Malone, 1981).

- Provide highly individualized instruction for students with a range of disabilities (Ellis & Sabornie, 1986).

- Promote positive attitudes toward learning. Students demonstrate more self-reliance and move toward independence (Brown, 1989) and regain a sense of being in control, which may lead to future success (Reiff, Gerber, & Ginsberg, 1992; Capper & Copple, 1985). Students with disabilities who gain competence with technology show a higher sense of self-esteem (Raskind, 1994).

- Facilitate cooperative, collaborative, and positive social behavior of students with disabilities (Dickinson, 1986; Rupe, 1986). Barton and Fuhrmann (1994) posit that students cooperate and collaborate more readily because of feelings of greater independence and relief from anxiety.

- Provide learner-controlled instruction (Kinzie, Sullivan, & Berdel, 1988), which can lead to feelings of competence and self-determination (Lepper, 1985).

- Provide active learning experiences to make learning more interesting, allowing students to attend to reading and read for longer stretches of time (Bialo & Sivin, 1980; Hecker, Burns, Elkind, Elkind, & Katz, 2002).

In 2001, the National Reading Panel (NRP) reported that available research on computer technology to facilitate reading skill development is limited, partially owing to the presumption by researchers "that reading instruction can be delivered *only* by a human" (NRP, p. 6–1). The panel concluded that students could, indeed, benefit from using computer technology for reading instruction because of emerging computer capabilities that support a complete reading program. Other technologies seen as promising by the NRP include text-to-speech (TTS) to print engines and the use of hypertext and supported word processing. NRP also called for more research on the use of voice recognition, hypertext documents, and Internet applications.

As technological solutions are applied to specific learning situations, the purpose of technology appears to fall into two categories: those that remediate specific skills through individualized and repetitive practice and those that compensate by bypassing the barriers of the disability (Edyburn, 2003b, 2003c; Day & Edwards, 1996). Deciding when to provide remediation supports (e.g., increased instructional time, drill and practice software) and when to provide compensatory intervention (e.g., providing a reader, human or technological, for a reading assignment) is critical to instructional design (Cook & Hussey, 2002; Edyburn, 2000; Maccini, Gagnon, & Hughes, 2002). As many reading researchers have suggested, the focus in the early grades is on learning to read, and the focus in the intermediate and upper grades becomes reading to learn. In determining the type of technology needed, the purpose must be established first. When does a teacher begin to focus on alternative strategies for understanding instead of continuing to remediate decoding skills and apply a technological intervention?

How the technologies are used is also influenced by the teaching pedagogy of the instructor but could be informed by a wider research base of efficacious applications of AT and AMT approaches. Although both uses of technology offer benefits for students with RDs, the compensatory approach may offer a more expeditious means of addressing significant difficulties (Raskind, 1994).

The overlap between remedial and compensatory functions is partly due to the fact that technological approaches frequently parallel best-teaching methods. Several such methods are embedded in reading technologies and, not surprisingly, in instructional uses of AT and AMT for reading development. Repeated reading, for example, is an effective instructional strategy that helps students with RDs develop reading fluency and increased comprehension (see reviews in Allinder, Dunse, Brunken, & Obermiller-Krolikowski, 2004; Meyer & Felton, 1999). When

guided through rereading the same passage, students decrease the number of word recognition errors, increase reading speed, and improve oral reading fluency and expression (Dowhower, 1994; Meyer & Felton, 1999; Reitsma, 1988; Samuels, 2002). When reading passages are presented on a computer with TTS, a nonjudgmental learning environment is created, where a student can reread the same passage with a fluent model as frequently as needed.

Another effective instructional strategy is the neurological impress method (NIM), in which a fluent reader models reading in very close proximity to a less-proficient reader. Traditionally for this strategy, a teacher-student pair read in unison, with the teacher setting the pace and tracking the text with a finger. This multisensory method builds a reader's fluency skills and diminishes some dysfunctional reading habits while building positive ones (Heckelman, 1986). The computer learning environment simulates this experience by pairing TTS with dynamic tracking, where the text being read is highlighted as it is spoken.

Both of these strategies adapt easily to the technological environment. Digital text is available for endless repetitions; dynamic highlighting tracks the text; and, when paired with TTS engines, an oral model creates an individualized, multisensory reading experience.

Methodology

The methodology we used to inform this report and develop the associated matrix is best described by Gersten and Baker (2000) as a multivocal synthesis (citing Ogawa & Malen, 1991). A multivocal synthesis capitalizes on the professional experiences and diverse practice backgrounds of the participants, bringing them together to create a wide-angle view of a complex research investigation. Opportunities for such exploration:

[E]nable researchers to conduct (an) open-ended search for relevant information, identify the major patterns associated with the phenomenon of interest, develop or adopt

constructs that embrace the patterns, articulate tentative hypotheses about the meanings

of the constructs and their relations, and refine questions and/or suggest conceptual

perspectives that might serve as fruitful guides for subsequent investigations (Ogawa &

Malen, 1991, p. 271).

A multivocal synthesis is suggested as an appropriate tool for investigations in a field

characterized by "an abundance of diverse documents and a scarcity of systematic

investigations" (Ogawa & Malen, 1991, p. 455). The field of reading research, RDs, AT, and

AMT, we posit, is just such a field.

Following is an overview of the variety of sources we used to investigate the

relationships between reading skill development and technology-based approaches.

Professional Work Group

NCTI, which is funded by the U.S. Office of Special Education Programs (OSEP),

advances learning opportunities for individuals with disabilities by fostering technological

innovation. We seek to broaden and enrich the field by providing resources and promoting

partnerships for the development of tools and applications by researchers, developers, and

vendors. Our primary objectives are to (a) cultivate a collaborative network; (b) promote

innovative technology-related products that reach the marketplace; and (c) analyze needs, issues,

trends, and promising technological innovation and transfer approaches.

As part of our work under the latter objective, NCTI's researchers recognized the need to

synthesize the research and literature on reading and technology and identify gaps in the current

research base. Therefore, we contracted with Ms. Sue Mistrett, Project Director, Assistive

Technology Training Online Project at the University of Buffalo, to lead the work group collaborations.

Over the course of a year, a team of researchers at NCTI, project directors at OSEP, consultants, and expert panelists explored the means of conceptualizing and representing the relationships between reading skill development and technological supports. Through conference calls, shared articles and reports, and e-mail exchanges, we shared alternate views of how to approach the representational task, the scope of the literature search, the intended audience, and the sources of unpublished research and studies already underway. Members of the reading and technology expert panel were Dr. Donald Deshler, Professor, University of Kansas; Dr. Sharon Vaughn, Professor, University of Texas at Austin; Ms. Ruth Ziolkowski, President, Don Johnston, Inc.; and Dr. Bart Pisha, Research Director, Center for Applied Special Technology. Consultants included Dr. David Edyburn, Professor, University of Wisconsin-Milwaukee; Dr. Skip Stahl, Research Director, Center for Applied Special Technology, and Dr. Terry Salinger, Managing Research Analyst, American Institutes for Research.

As befitting a multivocal synthesis, consensus did not come easily or fully. Comments from reviewers and expert panelists that reflect divergent opinions are presented in online commentary and dialogue stimulators.

Literature Search and Analysis

An extensive search of literature was conducted on technologies used to help develop reading skills and comprehension in students with RDs. Electronic searches for appropriate articles published from 1994 to 2004 were conducted with the following databases: PsychInfo, Exceptional Child Education Resources, Academic Search Premier, American Humanities Index, PsychARTICLES, Sociological Collection, Educational Abstracts, and Professional

Development Collection. Keywords used in generating a list of references included: alternative texts, storybooks, digital text, speech-to-text, reading technology, special education, DAISY Readers, electronic resources, reading education, graphic organizers, educational technology, text readers, and talking word processors.

Reference lists in articles and earlier literature reviews (Edyburn 2002, 2001, 2000; MacArthur, et al., 2001; Maccini et al., 2002) were examined to identify additional relevant articles, and an ancestral search of periodicals was conducted. Finally, contacting grantees of OSEP projects that address RDs and technology and requesting unpublished research findings to date identified additional sources on students with RDs and technology.

All abstracts were reviewed, and articles specifically related to technology use and children with RDs were selected. Complete articles were then reviewed for appropriateness based on the following criteria: inclusion of K–12 students with RDs or students at risk for RDs, reports of student performance data, reports presented in English, and investigation of an identified technological feature or product. Of the 115 reports retrieved, 29 met the criteria and are presented in detail in the online matrix described below. The following information is included, when available, for each study: author(s), title, abstract, journal name, research questions, research method and design, technological features investigated, numbers and ages of participants with disabilities, types of disabilities, and results.

The Ongoing Nature of the Matrices

The online matrices that accompanies this report are intended to be a repository of both published or otherwise publicly shared research and information on technology-based products. As was true for the selection criteria for this report, research will be included that reports efficacy data for technology-based approaches to building reading skills and comprehension for

students with RDs. The matrices are intended to be regularly updated by NCTI; therefore, there is no complete list of research and products. They will be maintained and updated quarterly by a team of researchers at NCTI, and new information will be solicited through our website and public dialogue generated by presentations of papers and matrices at professional conferences. Stakeholders and visitors to the website are encouraged to submit or suggest articles, abstracts, or product demonstrations for inclusion.

Limitations

This was an exploratory study that took a multivocal approach of a working group and conducted a literature review without predetermined categories. It is designed to be organic and responsive to research and software development. Nevertheless, it is undoubtedly incomplete. Although the expert panelists asked that evaluations of more software products be included in this paper, in reality, we were constrained by both space and the *lack* of evaluation research. We anticipate that the volume of research on AT and AMT for students with RDs will continue to increase and look forward to incorporating those studies and voices into the matrix.

Technological Approaches for Reading: Purposes, Strategies, and Examples

We identified six categories of technological purposes that have been used to support students with RDs. The categories were selected based on conversations among our professional working group members and through extensive reviews of reported interventions used with students with RDs, but the reviewed interventions are not intended to represent all possible solutions. Neither are the categories in any way bounded; rather, the nature of technology is the overlapping and continually expanding purposes, features, and creative uses by researchers, teachers, and learners (Leu, Kinzer, Coiro, & Cammack, 2004). This organization is by no means

the only way to represent the relationships between technology-based approaches and instructional purposes; see *Beyond the Text* (National Center for Accessible Media) and Edyburn (2003d). The remainder of this paper discusses the purpose, instructional strategies, educational contexts, and related research in each category.

Table 1 provides a general overview of the categories, the reading skills exercised, educational strategies for use, and products related to each category. Column 2 in the Table (Reading Skills & Strategies) attempts to synthesize various vocabularies and perspectives on reading development by including skills as described by multiple professional reading research efforts, including the National Reading Panel (NRP, 2001); the *Standards for the English Language Arts* published by the National Council of Teachers of English with the International Reading Association (NCTE-IRA, 1996); and *Targeted Instruction for Struggling Readers*, a resource provided by the U.S. Department of Education (Dickson, 2004). These perspectives on reading contain much overlap in what they consider essential skills and best instructional practices, but they also contain some unique elements. Column 3 (Educational Strategy: How It Is Used) is the result of many discussions and exchanges, from our various perspectives and experiences, consider to be the best uses of AT and AMT for students with RDs. Column 4 (Examples of Tools: Software & Devices) includes product examples, and while it is an admittedly incomplete list of products that can be used for the named purposes and strategies, they are represented and evaluated in the body of the paper.

Finally, the related searchable matrices (http://www.nationaltechcenter.org/resources.asp) presents an extensive list of research on and detailed information about products that are associated with each of the six categories. The matrix is not a static compilation, but rather a growing repository of information for new technologies and research. The matrix augments this

report and reveals gaps in the research and availability of current technological products to foster

new ideas for technological development.

Table 1. Overview of Technology Purpose Categories

Technological Purpose	Reading Skills & Strategies	Educational Strategy: How It Is Used	Examples of Tools: Software and Devices
Building reading skills and comprehension	**Specific Skills Focus** • Phonemic awareness • Phonics or alphabetic code • Fluency • Vocabulary • Word analysis • Fluency and automaticity • Spelling • Motivation	Practice specific skills to reinforce or remediate; progress monitoring	• Earobics • Fast ForWord • Simon Sounds it Out • Lexia Phonics-based reading • First Words/First Verbs
	Broad Focus (all of the skills cited above plus): • Comprehension strategies • Exploration of a wide range of texts • Application of a wide range of strategies • Participation in literacy communities	Use as supplemental reading instruction; progress monitoring	• Balanced Literacy • Simon Sounds it Out • WiggleWorks • Read 180 • Edmark Reading Program • Waterford Early Reading
	Comprehension • Use a range of comprehension strategies • Increase exposure to a variety of technological and informational resources • Participate in literacy communities • Engage in research	• Provides materials at different reading levels • Embeds hyperlinks to additional information • Probes, questions, elicits prediction and analysis	• Start-to-Finish Books • Digital textbooks • Thinking Reader
Converting text to speech (TTS)	• Phonemic awareness • Phonics or alphabetic code • Fluency and automaticity • Comprehension • Exploration of a wide range of texts • Engagement in research • Increasing exposure to a variety of technological and informational resources • Using language to accomplish their own purposes	• Read aloud any amount of text • Highlight text as it is read aloud to support tracking • Read and navigate the Internet • Customize text presentation as it is read aloud	• Simple Text (Apple) • Text Readers (ReadPlease, ScreenReader) • Talking word processors • Scan to Read programs (Kurzweil, WYNN, Read & Write Gold)

Providing text in alternate formats	• Phonemic awareness • Phonics or alphabetic code • Fluency and automaticity • Vocabulary • Word analysis • Comprehension • Increasing exposure to a variety of technological and informational resources • Participation in literacy communities • Exploration of a wide range of texts • Using a wide range of strategies • Application of knowledge of language to create and critique text • Motivation	• Increase engagement with talking storybooks • Combine text with symbols and pictures (rebus software) • Provide access to digital versions of print books and texts • Convert print to speech	• Living Books • Rebus Programs (Clicker4, News to You; Writing with Symbols) • Audio Supplements to Text (Read 180, Start to Finish) • Scan to Read programs (Kurzweil, WYNN, Read & Write Gold) • DAISY books, eReader, easEReader • Text to Audio (CoolSpeech, Audible.com, books on tape)
Providing electronic resources	• Phonics and alphabetic code • Vocabulary • Word analysis • Comprehension • Increasing exposure to a variety of technological and informational resources • Motivation	• Immediate access to dictionary for pronunciation and meaning • Online tools • Portable reference tools	• Reading Pen • Franklin devices • On-line resources (libraryspot.com, Visual Thesaurus)
Organizing ideas	• Comprehension • Application of a wide range of strategies • Application of knowledge of language to create and critique text • Increasing exposure to a variety of technological and informational resources • Motivation	• Arrange and easily rearrange ideas • Represent conceptual relationships • Switch from diagram view to outline view	• Outline view in many word processors • Kidspiration/Inspiration • Visio • DraftBuilder
Integrating literacy supports in a single application	Potentially, all of the skills and strategies cited above	E-Reading environment that converts TTS, manages e-books, including talking word processors and spell checkers with a range of embedded, at-the-ready supports	• Kurzweil • WYNN • Read + Write Gold • eReader

Building Reading Skills and Comprehension

Access to a variety of texts at any age is a critical component of reading because a range of literary experiences exposes a student to the sounds, rhymes, rhythms, and meanings of words of a language and provides new information about the world around them (Adams, 1990; Teale & Sulzby, 1986). Academic success is promoted by essential language skills, cognitive skills, and background knowledge that students acquire from engaging with text (Cunningham & Stanovich, 1998). According to Rose and Meyer (2002), the flexibility of digital media supports effective instruction in four ways. First, digital media are versatile and can be displayed and combined in a variety of formats. Second, digital media are transformable from one presentation mode to another and from one application to another. Third, it can be marked in ways that facilitate navigation and that emphasize a particular aspect of the content or text. Finally, digital media can be networked, supporting links to other forms of digital media as enhancements and resources.

Specific skills software. Computer software programs can assist students in acquiring the explicit skills needed for reading. Programs address skill acquisition through practice in individual reading skill areas such as phonemic awareness, alphabetics, fluency, vocabulary, and comprehension. These programs provide interactive activities that are self-paced, can be repeated as often as needed, and may provide visual and auditory cues for self-correction. In general, programs that foster reading-skill acquisition target young students; however, some provide age-appropriate strategies and content for older students.

Developing vocabulary is a key component of learning to read and comprehend and is a reciprocal process with text. For students with RDs, vocabulary, like other material, is learned best when presented and practiced directly and multimodally and in a meaningful semantic

context (see research syntheses of Bryant, Goodwin, Bryant, & Higgins, 2003; Jitendra, Edwards, Sacks, & Jacobson, 2004). For example, Laureate Learning Systems' programs, such as First Words and First Verbs, deliver vocabulary instruction through technology. These programs were developed from research in language acquisition and vocabulary development. In these programs, users are guided through systematic, cumulative vocabulary development activities that present words in categories and semantic contexts. Artificial intelligence software customizes and adjusts the language skills so that users can work at an appropriate challenge level or "optimized intervention" (Wilson, Fox, & Pascoe, 2003). Detailed student record-keeping software is also embedded to monitor student progress.

Earobics and Fast ForWord are specific skill software programs that provide interactive, game-like, specific-skill practice environments. Both programs are intended to boost the fundamental skills of young students who struggle with language and reading skills. They both offer practice in the subskills of phonological awareness, offering games for auditory recognition and discrimination and phoneme manipulation, etc. (Earobics has a version of its software that is designed for older students who struggle with fundamental skills.) A comparison study (Pokorni, Worthington, & Jamison, 2004) sought to determine the effectiveness of these programs on phonemic awareness, language, and reading-related skills of English-speaking students who received speech- and language-related services. A third program, Lindamood Phonemic Sequencing Program (LiPS) (Lindamood & Lindamood, 1998), which must be taught by a professional, was simultaneously compared with the software interventions. The investigation was conducted with 7.5- to 9-year-old students who attended a school district-sponsored summer school program. Fifty-four students were randomly assigned to one of the three groups and received the interventions, with the instructional support of trained graduate students, over a 20-

day schedule of three one-hour intervention periods per day. Findings from pre- and posttest measures of phonological awareness, language development, and reading-related skills indicated that, although the LiPS and Earobics groups both showed strong gains in phonological awareness that were maintained six weeks after the intervention, none of the programs was associated with significant transfer effects to language or reading achievement during the school year. Additionally, a significant number of students (46.3–93.8%) failed to achieve mastery of the concepts and continued to experience significant deficits in the language and reading areas assessed. The researchers hypothesized that student and program characteristics remain important variables in the success of remediation effects and encouraged more such evaluations of commercial software in authentic settings (Pokorni, personal communication, July 29, 2004).

Programs with broad skill focus. In addition to programs that build specific reading skills, several carefully sequenced curricula with extensive student tracking features build a series of interrelated skills required for reading. Students progress through literacy activities by gradually adding new skills. A management system follows student growth with results of each activity; students develop more complex skills. These curricula programs offer both e-books and tradebooks and frequently incorporate multimedia and interactive features such as graphics and text animation, music, friendly avatars to help a child know how to respond, and the capacity to recognize speech as a response to queries.

WiggleWorks, an integrated learning system for emerging literacy, was developed by the Center for Applied Special Technology (now distributed by Scholastic) to support early reading and provide built-in student monitoring. The program incorporates many customizable features, such as screen presentation color, size of text, recorded sounds, and read-aloud options, including word by word or line by line. It also supports interrelated instructional activities such

as reading, writing, and bookmaking. The program provides paperback tradebooks to accompany the digital books and activities. Schultz (1995) conducted a validation study of WiggleWorks. The intervention group who used WiggleWorks included 246 students in 29 first-grade classrooms among three districts; the comparison group contained 320 students. Results on the reading subtests and writing scales for the students who used WiggleWorks were quite strong—even disaggregated for below-the-mean and above-the-mean students.

Waterford Early Reading Program is an integrated learning system that has been extensively employed and evaluated in primary grades since its introduction in 1997. Designers of the program relied on reading research from the early 1990s, specifically Adams (1990), that showed significant advantages to children who are read to or have access to a wide variety of books in their early years. The designers developed a technology-based reading environment where students could work independently with literature and print 15 minutes a day. Level 1 activities emphasize print concepts, alphabetic automaticity, and phonemic awareness (Heuston, 1996).

Paterson, Henry, O'Quin, Ceprano, and Blue (2003) reported on an evaluation undertaken in an urban school district in western New York. They investigated whether the Waterford program had a positive effect on literacy learning compared with control classrooms, whether attitudinal changes were observed, and whether the computer-based learning transferred to regular classroom learning. The evaluation involved a mixed-method design that examined the use of the software and the literacy instruction in 25 kindergarten and 2 first-grade classrooms over the course of a school year. The findings concluded that the Waterford system did not have any significant effects on students' reading and literacy, nor did it reduce the achievement gap for students who began school with less-developed skills. Instead, the investigation found

significant literacy acquisition advantages for children in classrooms "where teachers facilitated children's active engagement in instruction [which] demonstrated a number of best practices . . . whether they were in classrooms that used the Waterford program or not" (p. 199).

This report sparked a debate in *Reading Research Quarterly*, with a Letter to the Editor that challenged the findings based on study limitations (White, 2004), a response providing further details of methodology by Paterson (2004), and a commentary by the journal's editor (Labbo, 2004). Labbo concluded that such healthy debate of contextualized studies helps researchers and developers "continuously reexamine the contextual factors under which [integrated learning systems] function most effectively" (p. 8).

Building comprehension. The primary purpose of reading is to comprehend the content presented. Comprehension occurs when the reader displays strategic analysis and resourcefulness (Farstrup & Samuels, 2002). Comprehension is a mental process that depends on readers combining their prior knowledge and experience with information in the text. Students need to be exposed to text in various formats and read and discuss whole texts with their teachers and peers in order to fully comprehend. Teachers use many strategies that support and guide comprehension, such as rereading, summarizing, predicting, questioning, clarifying, and writing. Teachers and readers can use these strategies at any time during the reading process to monitor understanding.

The repertoire of research-based strategies for students with RDs includes those listed above and also compensatory strategies that provide access to the text, thereby avoiding barriers presented by a disability. These compensatory techniques include providing the text auditorily to compensate for decoding difficulties, embedding language supports to build vocabulary, and using prompts to monitor attention and memory breakdowns. An example of this type of

software is Thinking Reader, a series of popular middle school tradebooks available in digital

format with embedded research-based comprehension strategies and study supports. The

program includes student progress monitoring features that capture students' access to the

embedded features and their path through the text. Field testing in middle schools with struggling

readers (performing at the 25th percentile or lower) revealed that students who were taught in

classrooms with Thinking Reader made more gains on reading achievement tests than students

taught comprehension strategies without Thinking Reader (Dalton, Pisha, Eagleton, Coyne, &

Dysher, 2001).

Converting Text to Speech

TTS, or speech synthesis technology, converts ordinary ASCII or other textual

information into synthesized speech that closely resembles natural speech so that it can be read

aloud by a computer. TTS engines can be an optional feature included in reading software

programs, or the engines can be specialized text readers. They are specialized tools that read only

compatible files, such as Talking Browsers that read web pages and TTS engines that read text in

any software application (word processors, spreadsheets, database, web pages, e-mail, etc.).

Some TTS programs have been designed for special populations (e.g., people who are blind,

cognitively impaired) but are not addressed in this report. Speech engines vary in the quality and

variety of voices provided. TTS programs also range in the availability and ease of adjustable

features such as text and background colors and contrast, reading rate, and highlighting and

masking.

A long-standing best practice for students with reading and learning disabilities is to use

instructional approaches that build on multisensory engagements with the material. Students who

learn best with both auditory and visual supports will benefit from an AT and AMT feature that

highlights text that is simultaneously read aloud, a feature available in most TTS engines. In one study (Montali & Lewandowski, 1996), when text was presented in both auditory and visual modalities, the comprehension of students with RDs was found to be similar to average readers who served as control students.

Dynamic highlighting, which colors the background of a single word or phrase so that it captures the reader's attention, emphasizes the text that is being read and helps readers maintain their place with the auditory input. Dual highlighting, sometimes called masking, is a related software feature in which the context (sentence or paragraph) is highlighted in one color and the spoken word is highlighted in another color, which strengthens the contextual placement of words.

TTS helps special education students improve comprehension, fluency, and accuracy and enhances concentration (Leong, 1992; Lundberg & Olofsson, 1993). Word recognition skills also improve with this technology (Olson & Wise, 1992). Being able to immediately decode a word by hearing it spoken within the context of a passage helps students build word recognition and vocabulary without disturbing the flow of comprehension (Califee, Chambliss, & Beretz, 1991). Comprehension is augmented by supporting decoding, thereby freeing the listener to focus on the meaning of the text (Wise, Ring, & Olsen, 2000). These technologies provide a supportive reading environment and increase a student's ability to read interesting and appropriate grade-level materials by minimizing the need for decoding skills and maximizing the student's ability to comprehend.

Providing Text in Alternative Formats

Interactive multimedia CD storybooks. Researchers have examined the use of hypermedia-based children's literature programs, also known as talking storybooks. In an OSEP

project, Lewis (1998) found more than 300 stories in this format. These programs read stories aloud in realistic, digitized human speech accompanied by colorful graphics. Students interact with both the text and the graphics in the stories. Many stories are developed for emerging readers and use simple illustrations and repetitive, rhyming, alliterative language to promote early literacy skills. Talking storybooks are interesting and motivating, are interactive and engage students' attention, and support the emerging reading process by reading text aloud (Musselwhite, Erickson, & Ziolkowski, 2002). Many are packaged with an interactive CD and tradebook so that students can read along with both formats.

Research also suggests that multimedia storybooks have limitations. Young students with RDs, or who are at risk for RDs, will "most likely require explicit instruction in skills such as decoding" (Lewis & Doorlag, 1995, p. 274) to accompany any digital presentation of reading instruction. Explicit instruction embedded in digital storybooks, although "intuitively appealing" (McKenna, 1998, p. 52) to researchers and teachers, can been seen as intrusive by readers and has produced mixed results in exploratory studies of children's engagement and reading development (e.g., Farmer, Klein, & Bryson, 1992; Greenlee-Moore & Smith, 1996; McKenna, 1998; Olson & Wise, 1992).

Text and pictures. Using pictures together with words (rebus) not only strengthens the association of text with vocabulary but also allows struggling readers to comprehend what is written. This strategy is recommended as one that should be found in every classroom with emergent readers (Bickart & Dodge, 2000; Dyson, 1989). In rebus books, words or parts of words that may be beyond a student's reading ability are shown with pictures to "prepare children to read by themselves" (Snow, Burns, & Griffin, 1998, p. 181). The word-pictures draw attention to key concepts in the text and help develop early vocabulary. Rebus symbols reinforce

language by providing visual prompts. Seeing words illustrated makes the text more meaningful and easier to remember. This strategy has been reported as being effective in improving reading outcomes of students with disabilities (Love & Litton, 1994). Using pictures as word banks can also aid the writing process for many students.

Several software programs automatically associate pictures and text for improved reading experiences. Often marketed as writing programs, they are also used in the classroom to promote independent reading and comprehension. Some programs are equipped with TTS engines to provide auditory support. Picture libraries are included, which may contain photographs, line drawings, or motivating animations. Some programs have the capacity to import personal digital pictures or created graphics.

Text at alternative levels. Students who are still struggling with reading when they reach the upper elementary, middle, and high school grades find it very difficult, if not impossible, to catch up. The combination of deficient decoding skills, lack of practice, and difficult reading materials results from unrewarding early reading experiences. This pattern then leads to less involvement in reading-related activities, especially when the reading materials differ from content offered to other students (Cunningham & Stanovich, 1998). Yet learning in the content areas through the secondary years requires efficient and functional reading abilities. With older students, it is increasingly important to provide content based on their interests and on their cognitive, rather than reading, levels (Calfee, Chambliss, & Beretz, 1991; Fielding & Pearson, 1994). When these skill levels diverge, efforts should be made to provide access to grade-level content. AT and AMT approaches are available for students reading below their grade level. These approaches are often combined with features to aid comprehension, such as dynamic highlighting, TTS, electronic references, and annotation capabilities.

READ 180 is a multimedia reading program that helps students with RDs accomplish grade-level literacy tasks. The program was developed in the Cognition and Technology Group at Vanderbilt University and is now distributed through Scholastic Inc. The program combines adjustable TTS, hyperlinked instructional videos, closed captioning, graphic organizers, comprehension strategy prompts, and continuous student progress monitoring. The capacity to customize a reading path through the software by using features and hyperlinks has been shown to be one of the strongest motivational aspects of this type of software and is associated with gains in reading skills (Hasselbring, Goin, & Wissick, 1989; Jonassen & Mandl, 1990).

For many students with RDs, print materials create barriers to access and therefore to learning. Students with different sensory, physical, and cognitive impairments need different supports to access printed text (Dyck & Pemberton, 2002). When reading materials are digitized, text becomes flexible and can be reformatted or transformed into accessible alternative formats of the same material for any student. Once digitized, text can be enlarged or presented in high contrasting colors to make it easier to see, matched with a speech engine to hear it read, and translated into other languages for non-English-speaking students. Students can turn pages with a single switch, hear word definitions spoken, or click embedded links for multimedia depictions of the content for increased understanding (Boone & Higgins, 2003; Rose & Meyer, 2002).

Locating existing digital versions of tradebooks and classroom text can save time for teachers. Many digital versions can be found from publishing distributors and Internet libraries. The newly released National Instructional Materials Accessibility Standard (NIMAS) (discussed below) encourages publishers to produce materials in a variety of alternate formats. Throughout the remainder of this section, we provide several promising approaches that combine digital text features, such as embedding electronic resources (prompts and reference materials) and attaching

additional information through hyperlinks. These approaches have tremendous potential for improving students' comprehension and promoting in-depth learning (Anderson-Inman & Horney, 1998, 1999).

E-books and e-libraries. Three areas of technology combine forces to create e-books: the reading content files, the software interfaces that package and present the files, and the hardware devices that allow the files to be read (handheld, laptop, or PC). Anderson-Inman and Horney (1999) consider e-books to have the following features: visible digital text, the functional metaphor of a printed book, an organizing theme, and any multimedia additions that enhance the text. E-books, therefore, allow a linear path through the text, although many are enhanced with hyperlinks and embedded multimedia features that also allow nonlinear explorations of the text and links. Many types of e-books are available online, either free or for purchase.

Although e-books are not new to the AT and AMT scene, their portability and availability have greatly increased with the introduction of e-book reader software that is compatible with personal computers rather than restricted to dedicated devices (Cavanaugh, 2002). Some of these reader software programs, such as Microsoft Reader, embed TTS so that readers can listen while following along with the text. Navigational and study skills tools are also embedded in Microsoft Reader, allowing users to search and find text, highlight and add bookmarks in multiple colors, create text annotations, and use an embedded dictionary with a right click. Annotations can be opened or extracted separately and formatted in a word processor.

E-libraries provide e-books for downloading. Some of the books are free; most of them are classics for which the copyrights have expired. University of Virginia's e-library and the Project Gutenberg library both hold more than a thousand titles in multiple file formats. Online booksellers are publishing and selling new works as downloadable files at prices comparable to

prices for printed books. Publishers of commercial leisure and instructional materials are increasingly publishing digital versions or supplemental materials (Poftak, 2001). With the release of NIMAS, more e-text will be provided in formats accessible to all students (see the Future Steps section below).

For individuals with documented print-related disabilities, subscription sites (such as Bookshare.org and Recordings for the Blind and Dyslexic) offer e-books of all types for members to download. In 1996, the federal copyright law (P.L. 104-197) was amended to provide alternative formats of reading materials for persons with print disabilities (National Library Service for the Blind and Physically Handicapped, 1996). These formats include "Braille, audio, or digital text which is exclusively for use by blind or other persons with disabilities." Also known as the Chaffee Amendment, this bill defines eligible persons as U.S. residents who have a visual impairment, a learning disability, or a mobility impairment that prevents them from reading printed text. Users must prove their eligibility by offering documentation of a print disability that prevents them from effectively reading standard print. This documentation allows the user to subscribe to organizations that offer a range of digital materials in different formats.

Audiobooks. Recorded audiobooks are a more popular format than ever. Teachers have long recognized the benefits of having students hear a book read as they follow along with a printed copy. Students' comprehension and vocabulary skills have been shown to significantly improve when bimodally seeing and listening to text (Montali & Lewandowski, 1996; Robinson, 1966; Steele, 1996). Listening without visual text, however, has not proven effective for students with RDs (Boyle et al., 2003; Maccini, Gagnon, & Hughes, 2002). Many recorded books include the audiobook and printed book together so that students can follow along in the print version

while they listen to the narration. This combination can support students with reading fluency and comprehension difficulties to access independent reading.

Commercial audiobooks are available on tape cassettes, on CDs, and as digital files, either text- or audio (compressed MP3 formats) based. Many tape formats with human-narrated recordings are being converted to the more flexible digital format. In fact, Recordings for the Blind and Dyslexic is currently reformatting all books on tape to a digital DAISY or NIMAS format. Each format uses a separate player technology—tape recorder, CD player, personal digital assistant (PDA), MP3 player, or specific hardware devices for DAISY books. Digital audio files can be used on computers with special playback software and on portable players, so students can hear reading materials read at any time in any environment—at home, at school, or on the bus. Most recorded books have the capacity to adjust the playback rate; books created in the DAISY format offer extensive speed adjustments and allow users to add bookmarks and access page numbers and headers so that they can efficiently navigate the book (Jolley, 2002). Innovative technologies (e.g., Plextalk player and recorder) allow anyone to record his or her own version of a DAISY audiobook. Such players also play commercial audiobooks, commercial music CDs, and MP3 files.

Boyle et al. (2003) evaluated the effectiveness of audio versions of general social studies (government) content material. Three groups of secondary students with mild cognitive impairments were provided with one of the following: (a) regular print textbooks; (b) textbooks and an audio CD with embedded navigational DAISY markups; or (c) textbooks, the audio CD, and training on a note-taking strategy. The strategy, called SliCK (Set it up, Look ahead, Comprehend, and Keep it together), was developed for secondary students. Three groups (17, 21, and 29 students, respectively) were studied during the six-week intervention that included two

textbook chapters. Both the audio + textbook and the audio + textbook + strategy groups outperformed the textbook-only group on the quizzes and cumulative test scores. However, the note-taking strategy was not found to be helpful, perhaps because of the lack of note-taking skills and prior note-taking experiences of the students. The results of this investigation indicate that compared with independent textbook reading, using an audio textbook can be an effective tool for increasing content acquisition of high-level academic content over time.

Providing Electronic Resources

Although we were able to locate only one research study that directly investigated the use and benefits of electronic resources for students with disabilities (Edyburn, 1991), teachers and students have long relied on these practical tools to support the literacy learning process and literacy activities. Using print-based resources to look up the meaning and spelling of words or to research information can be a cumbersome, yet necessary, task for students with RDs because of their difficulties with managing alphabetization, decoding, comprehension, and distractions.

Dictionaries with syllabication and pronunciation guides, encyclopedias, and thesauri are resources needed by all students. Electronic devices that do one or more of these tasks to support students are increasingly found in classrooms. Electronic resources encompass handheld technologies (e.g., handheld dictionaries and PDAs), software programs (e.g., Encyclopedia Britannica), and online resources (e.g., Visual Thesaurus and various search engines). Many are paired with TTS, adding the benefits of a bimodal presentation of text that was discussed earlier.

Many handheld reference devices include TTS options to hear the word and its spelling or definition. For example, Franklin Electronic Publishers offers a range of portable reference devices, including dictionaries, thesauri, encyclopedias, and books of quotations. The Reading Pen, produced by Wizcom Technologies, is a ballpoint-pen-sized scanner loaded with the

American Heritage Dictionary. When a user slides the pen across a word or a line of text, the text is scanned into the pen and can be read with TTS, providing auditory support for a single word, a definition, or a connected line of text.

Organizing Ideas

Instructional approaches often augment comprehension through visual strategies that use advanced organizers, structured overviews, knowledge maps, story maps, and concept maps. Known as graphic organizers, these strategies offer visual and graphic displays that depict the relationships among facts, terms, and ideas within a learning task (Hall & Strangman, n.d.). Two syntheses of the effectiveness research on the use of graphic organizers concur that the technique elevated reading comprehension and vocabulary development of students with learning disabilities (Kim, Vaughn, Wanzek, & Wei, 2004; Hall & Strangman, n.d.).

Using graphic organizers has generally been a teacher-directed large-group activity that focuses on relationships among reading components to aid comprehension (Hall & Strangman, n.d.). Technology-based versions can use hyperlinks to connect related information. For example, words and/or images and/or animations can be linked, making connections easier to comprehend. Therefore, technology-based graphic organizers can expand the instructional use of traditional graphic organizers by providing a highly flexible learning environment that is adaptable to individual users (Castellani & Jeffs, 2004). Additional features in these software programs include TTS engines, graphic symbols, representations of multidimensional relationships, and alternating graphical and outline views.

Students with attention, organizational, and learning disabilities have shown increased academic gains when exposed to technology-supported concept-mapping strategies (Anderson-Inman, Knox-Quinn, & Horney, 1996). AT and AMT graphic organizers that allow students to

freely design interactions in the graphical mode and then reorganize them in the outline view provide students with increased clarity of the connections within the material they are representing (Bisagno & Haven, 2002).

Integrating Literacy Supports in a Single Application

Software programs that integrate many literacy support features provide an enriched personal learning environment in which students can read and complete, in an accessible digital format, the same grade-level reading and writing assignments and assessments as their peers. These programs have the capacity to be networked to other AT and AMT stations, scanners, printers and to the Internet. They combine highly customizable features of TTS, word processors with spell checkers, and Internet browser supports. They have a wide range of embedded study supports and resources, such as multiple highlighters, annotation devices, bookmarkers, dictionaries, thesauri, and pronunciation guides, which are embedded in the toolbars and can be accessed easily.

Text can be imported from scanners through optical character recognition software, which digitizes paper-based text, or imported as a digital file from other computer files or from downloaded e-books. Programs with proprietary scanning preserve the layout of the scanned page so that the image and pagination on the screen appear in the exact same layout as in the original. Annotations (on digital "sticky notes" or margin notes) can be saved, exported, and reformatted for further study. Some programs embed monitoring software that can track what features students access while reading, how long they use the feature, and what path they follow through the file. This type of detailed data will be essential to increasing our understanding of how these programs work for students and how students work with these programs.

Future Steps

With the abundance of AT and AMT available today, how do students with RDs or their teachers determine what approaches are best in certain situations? Although AT and AMT approaches have long been described in anecdotal reports as motivating, equalizing, or successful, only limited evidence-based research is available to guide the selection of a tool in response to a student's needs and purposes.

With technology-based approaches becoming more common in today's classrooms, efforts are underway to ensure access to these approaches for all students. Publishers and vendors will respond to access standards that adhere to copyright statutes and offer readable, understandable formats for all students. NIMAS, announced in July of 2004 (http://www.ed.gov/news/pressreleases/2004/07/07272004.html), requires publishers of instructional materials to provide an electronic file of all new textbooks in a consistent and well-structured file format, and states will be required to establish distribution processes for ensuring that these files are made available to all qualified print-disabled students. NIMAS goes into effect two years after the reauthorization of the Individuals with Disabilities Education Act, (not yet passed at the time of publication). With the increased use of websites as part of instructional materials and with more publishers offering digital versions and supplemental materials on the Internet, accessibility standards for websites must also be embraced by developers to ensure full accessibility.

Creating supportive learning environments for all students is as important as accessibility standards; simply giving students *access* may not maximize the full extent of technology's potential. Other technological approaches should be examined that can make learning appropriate for each student—those with and without disabilities. Technological features (e.g.,

TTS, text highlighting, hyperlinked reference tools, alternative formats, and built-in comprehension prompts) can support learning engagement.

Throughout this paper, all studies conducted in real-life learning contexts with students with RDs find that learner characteristics still override any broad statements of effectiveness (Labbo, 2004; Pokorni, Worthington, & Jamison, 2004; Torgeson, 2000; Wise, Ring, & Olson, 2000).This highlights the need for software developers and educational researchers to continue to pay attention to and build products, learning environments, and evaluation criteria for a wide range of student abilities, profiles, and preferences.

The tenets of Universal Design hold that products, curriculum materials, and experiences need to be designed with as much flexibility and customizability as possible (Pisha & Coyne, 2001). When preference features are embedded in AT and AMT, teachers and students are able to choose the most efficacious presentation mode and strategic supports. Embedded features are available for students who need them, invisible to those who do not, and adjustable and removable to accommodate students' mastery of skills.

Exploring Gaps and Preparing for Change

Researchers from various domains that contribute to research development and evaluation in the areas of literacy, technology, and special education have recognized the limited research base on the efficacy of using technology with students with RDs and have proposed dialogues on setting a research agenda (Edyburn, 2004; Kamil & Lane, 1998; Leu et al., 2004). The Assistive Technology Outcomes Measurement System project emphasizes importance of researching the learner-technology interactions with specific features. Leu and colleagues (2004) question the assumptions held by researchers and teachers about literacy, learning, teaching, and

the role of technologies. Kamil and Lane (1998) remind researchers of gender, language, and power equity issues embedded in the use of technology in the classroom. Taking these related sets of concerns into account, we suggest a dialogue on setting a research agenda for the role of AT and AMT in the teaching and learning of reading for and by students with RDs. The following questions are critical to explore:

- Given the "transactional relationship" (Leu et al., 2004) between technology and literacy, how must our understandings, definitions, assumptions, and research paradigms around reading change?

- How can we keep consumer satisfaction (i.e., the user's experience) as a paramount concern in the instructional, research, developmental, and evaluation processes? What outcomes and whose outcomes count as successes?

- As we work toward more inclusive and accessible learning environments, how can we ensure that unique needs requiring accommodations are still addressed?

- What terms subsume which features? How can we learn which of the many features available in AT and AMT are helpful or how those features can be used most productively for which students in which situations?

- How can researchers and practitioners work with developers to best respond to the literacy needs of students with disabilities?

- In what ways are new technologies and new literacies challenging existing understandings, assumptions, definitions, and research paradigms of disabilities?

We at NCTI look forward to engaging the field in dialogue and being part of the transformational processes in an effort to advance learning opportunities for individuals with disabilities. We encourage all stakeholders to review the contents of the associated matrices (see

NCTI

link on http://www.nationaltechcenter.org/resources.asp). All research and products on the

matrices can be searched by each of the six categories. We hope to contribute to the field by

continually updating this matrix as new research is conducted and technology is developed and

by building a comprehensive source of research and products to assist students with RDs as they

learn to read. Please contact us at NCTI@air.org if you have any recommendations for additional

research or products that should be added.

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