# Technologies That Support Students' Literacy Development

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**Abstract**

This chapter reviews recent research on technology that supports students' developing literacy skills from preschool through high school. We examine technologies for students across three developmental periods of reading: emergent literacy (preschool through kindergarten); learning to read (kindergarten through third and fourth grade) and reading to learn (third grade through high school). In general, when used with students' learning needs in mind, literacy software can effectively support students' acquisition of skills throughout these developmental periods. However, accumulating evidence reveals that good software will not replace good or even adequate teaching unless it is used with attention to optimizing instruction to meet students' individualized learning needs both face-to-face and on computers. We also review the role of technology in assessment of literacy skills and present promising results. In general, technology can provide an environment that supports reliable and valid assessment, especially when automated scoring can assist teachers in the assessment of students' basic skills, writing, summarizing, and synthesizing information across multiple texts. Finally, we review technologies that support teachers' efforts to provide more effective literacy instruction. Overall, current research indicates that technology-based professional development and specific software applications that support teachers' ability to individualize student instruction using assessment are generally effective in improving students' literacy outcomes.

**Keywords**

Assessment • Professional development

## Technologies That Support Students' Literacy Development

Children with weak literacy skills face serious challenges throughout their school career and beyond. They are more likely to be retained a grade, be referred for special education services, to drop out of school, to enter the juvenile criminal justice system, and to have limited career options (Hernandez, 2011; Reynolds, Temple, Robertson, & Mann, 2002). The most recent NAEP results show that almost one-third of students fail to achieve even basic reading skills by fourth grade (NAEP, 2011). The situation is even less encouraging for students beyond fourth grade: NAEP reading scores for high

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J.M. Spector et al. (eds.), *Handbook of Research on Educational Communications and Technology*, DOI 10.1007/978-1-4614-3185-5_47, 

school students are no different from those in 1971 National Assessment of Educational Progress (NAEP, 2009), remaining relatively flat over the past 40 years (Heller & Greenleaf, 2007; Perle et al., 2005). Results of the 2007 NAEP writing assessment, administered to 8th and 12th graders, show equally flat results: 35% of 8th and 25% of 12th grade students scored at the proficient or advanced level, with no increases in these percentages compared to the 2002 administration (National Assessment of Educational Progress (NAEP), 2008). These data reflect the difference between basic reading skills and skills needed to use reading and writing to solve problems, make decisions, find answers, and function well within our information society (Goldman et al., 2011; Shanahan & Shanahan, 2008). These skills are prominent among the literacy demands of the twenty-first century and their importance is reflected in the recently published Common Core State Standards in English Language Arts, History/Social Studies, Science, and Technical Subjects (CCSSO, 2010) and the National Educational Technology Plan (NETP, US Department of Education, 2010). Education professionals, researchers, and policy makers recognize the need to develop methods and interventions designed to improve students' development of reading and writing skills at both basic and complex levels. In this chapter, we review the recent knowledge base on effective uses of technology and promising emerging applications that focus on students' literacy development and on supporting more effective literacy instruction.

The articles and chapters selected for this review met three criteria: First, they had to be published in peer-reviewed journal articles, federal reports, or chapters in books. Second, only recent publications, most published in the past 5 years, were included. Readers are referred to two reviews completed in 2001 and 2002 (Blok, Oostdam, Otter, & Overmaat, 2002; MacArthur, Ferretti, Okolo, & Cavalier, 2001) for older studies. Finally, publications had to be about literacy from preschool through high school. Research with adults, including college students, was not included in this review. We used typical electronic search procedures and concentrated on technology projects with evidence of documented efficacy defined by the IES What Works Clearing House as "interventions [that] produce a net positive impact relative to a counterfactual when they are implemented in authentic education delivery settings (e.g., schools). …" (http://ies.ed.gov/funding/pdf/2012_84324A.pdf, p. 45). We did, however, include highly promising technologies for which there was quasi-experimental evidence.

In this chapter, we consider technologies relevant to three developmental periods of reading: *emergent literacy* (Lonigan, Burgess, & Anthony, 2000), *learning to read*, and *reading to learn* (Chall, 1996) and provide an overview of the skills students are developing in each. Then we review the research on three areas of reading and writing technology: (1) technologies that students use directly in order to improve their reading and writing skills; (2) technologies designed to facilitate assessment of students' reading and writing skills; and (3) technologies designed to support teachers' efforts to provide more effective literacy instruction. We conclude with recommended directions for research and development of technologies for reading and writing.

## Research on Language and Literacy Development

*Emergent Literacy.* For typically developing children, preschool, or roughly ages 2–5 years, is the time frame for emergent literacy, a period of tremendous growth in oral language and awareness of print (Teale & Sulzby, 1986), nascent phonological awareness, and emergent grasp of the alphabetic principle (Lonigan et al., 2000). Phonological awareness is the ability to consciously manipulate the phonemes of the English language (e.g., What are the phonemes in the word "bat"? /b/ /a/ /t/). Phonological awareness appears to facilitate grasp of the alphabetic principle: that phonemes map onto letters in fairly predictable ways (grapheme–phoneme correspondence) and that these graphemes combine to form meaningful words. Preschoolers begin to grasp these concepts and they are mastered in kindergarten and first grade for most children (Ehri, 2002). Weak phonological awareness and failing to grasp the alphabetic principle is a characteristic of many children with reading disabilities or dyslexia (Vellutino, Fletcher, Snowling, & Scanlon, 2004). At the same time, young children are bringing their developing oral language, including vocabulary, to bear in the understanding of text. This link, too, appears to develop in fairly predictable ways (Scarborough, 2001).

*Learning to Read.* The transition to learning to read begins with the onset of formal schooling—kindergarten and first grade for many children—and continues through third grade, roughly ages 4–8 years. Effective instruction during this phase includes explicit focus on the critical component skills of reading: phonological awareness, phoneme–grapheme correspondence, word recognition, vocabulary development, fluency, and comprehension (NICHD, 2000) as well as writing. As children learn to read and write, their ability to decode and encode words becomes increasingly fluent. Their application of their oral language skills to understanding and writing text becomes increasingly strategic (Scarborough, 2001) until they move beyond learning to read and begin to read to learn (Chall, 1996) There is substantial overlap for the phases and *reading to learn* can be introduced as soon as children have begun to recognize printed words and even before through oral language.

Whereas there is substantial research on how students learn to read, there is much less on how students learn to write and use writing for learning (Harris, Santangelo, & Graham, 2008). Research shows that explicit instruction in planning (Graham, Harris, & Mason, 2005) and revising (Matsumura, Patthey-Chavez, & Valdés, 2002) appears to support students' writing development as do opportunities to write and specific instruction in writing (Moats, Foorman, & Taylor, 2006). Effective writing instruction has been described as a sequence of instructional activities including planning, instruction, writing, and editing and revising, and then writing again (Harris, Graham, & Mason, 2006; Hayes & Flower, 1987).

*Reading to Learn.* Emerging as early as first and second grade, *reading to learn* becomes the dominant instructional focus by fourth or fifth grade, when students are about 8 or 9 years old. Reading becomes a principal mode for learning, with students expected to acquire new knowledge from written language, including important content area concepts and principles. Doing so draws on morphological and syntactic knowledge, comprehension strategies, and increasingly sophisticated cognitive and metacognitive skills needed to think critically and broadly (Chall & Jacobs, 2003; Connor, 2011). Students learn to employ strategies such as summarizing, finding main ideas, learning vocabulary in context, and making inferences (Guthrie, Anderson, Aloa, & Rinehart, 1999; Snow & Biancarosa, 2003). Key also is learning from discipline-specific texts and tasks that require specialized ways of reading and writing (Goldman & Bisanz, 2002). Discipline-based, reading-to-learn instruction takes into account the way knowledge is created and communicated within the discipline, including the purposes associated with specific genre, language and discourse conventions.

Literacy does not develop spontaneously or in isolation, but rather in the broader contexts where learners interact with others and with materials, especially at home and in the dynamic learning environment of the school classroom (Bronfenbrenner & Morris, 2006; Morrison & Connor, 2009). Thus, the role of technology for promoting literacy is considered here in the context of schools and classrooms and therefore includes not only the technologies designed to be used by students, but tools that support learning, assessment, and teachers' ability to provide effective literacy instruction.

## Technology Designed to Be Used by Students

### Technology for Supporting Emergent Literacy

We found few preschool studies that met our standards for inclusion in this review and those we did find had conflicting findings. We review what we found here, but clearly more research is needed in this area.

Huffstetter and colleagues (Huffstetter, King, Onwuegbuzie, Schneider, & Powell-Smith, 2011), examined whether *Headsprout Early Reading* supported preschoolers' ($n=62$) oral language and early reading skills. *Headsprout* employs a sequence of animated, interactive lessons to help students learn phonological elements and sight words, in order to build their reading vocabulary. Results of this experiment, in which preschoolers were randomly assigned to condition, revealed that preschoolers who used *Headsprout* daily for 8 weeks made significantly greater gains in early reading and oral language skills compared to preschoolers in the control group.

Preschoolers who attend to text while their parents or teachers read to them tend to learn to read more easily. However, many preschoolers do not attend to printed words during shared book reading, with negative implications for late literacy learning (Justice & Ezell, 2002). Gong and Levy (2009) investigated whether electronic books might enhance preschoolers' attention to print. They found that when children ($n=96$) used e-books that increased their attention to print they made greater gains than when they simply listened to the e-book.

Technology integration does not always enhance instruction. Davidson and colleagues (Davidson, Fields, & Yang, 2009) compared reading gains for prekindergarteners ($n=257$) randomly assigned to classrooms using the HighScope district curriculum with those using the same curriculum but with an integrated technology component, *Ready*, *Set*, *Leap*! They found no significant differences in preschoolers' literacy gains.

### Technologies and Learning to Read

Among the most important studies on early elementary reading technology, the study on the *Effectiveness of Reading and Mathematics Software Products*: *Findings from the First* (*and Second*) *Student Cohort*, a national evaluation of education technology, was conducted during the 2004–2005 and 2005–2006 school years at the request of the US Congress (Campuzano, Dynarski, Agodini, & Rall, 2009; Dynarski et al., 2007). In this large-scale study, teachers and their first or fourth grade students, within schools (Cohort 1: 11 districts, 43 schools, 158 teachers and 2,619 students in first grade and 11 districts, 43 schools, 118 teachers, and 2,265 students in fourth grade), were randomly assigned to a business-as-usual control or to use one of several selected reading software packages (see Table 47.1). This study was designed to test the impact of technology that made its way into schools through current district and school decision-making and implementation processes.

The first grade software packages selected for the study tended to focus on code-related skills such as phonological awareness and phonics whereas the fourth grade packages tended to focus on reading comprehension. Packages,

**Table 47.1** Products included in the national evaluation of education technology in cohort 1 and cohort 2 (as indicated)

| Software package | Grade | Publisher | Web sites |
|---|---|---|---|
| Destination Reading | 1 | Riverdeep | http://web.riverdeep.net/ |
| The Waterford Early Reading Program | 1 | Pearson Digital Learning | http://www.waterfordearlylearning.org/ |
| Headsprout | 1 | Headsprout | http://www.headsprout.com/ |
| Plato Focus | 1 | Plato | http://www.plato.com/elementary-k-6 |
| Academy of Reading (not in cohort 2) | 1 | Autoskill | http://eps.schoolspecialty.com/ |
| LeapTrack | 4 | Leaptrack | http://shop.leapfrog.com |
| Read 180 (not in cohort 2) | 4 | Scholastic | http://read180.scholastic.com/reading-intervention-program/about |
| Academy of Reading | 4 | Autoskill | http://eps.schoolspecialty.com/ |
| Knowledgebox (not in cohort 2) | 4 | Pearson Digital Learning | No Web site available |

selected from among products that developers and publishers submitted for consideration, met several criteria with the most important being evidence of efficacy, the ability to be implemented in large numbers of classrooms simultaneously, and the availability of teacher training. Schools chose the software package they wanted to use. Teachers in the treatment group received any requested technical assistance and were provided computers and other technology, such as headphones, servers, and printers. This support was not provided to teachers in the control group. Teachers generally received about 1 day of training at the beginning of the school year and ongoing support. They used the products, on average for 48 h/year for first grade and 40 h/year for fourth grade. In general, these procedures would tend to increase the potential impact of the software packages on student outcomes when compared to the control groups.

The five first grade products listed in Table 47.1 had much in common. In general, they all offered tutorial and practice opportunities for students and provided feedback to students and teachers. Three of the 4th grade programs assessed reading skills and then offered students practice in aspects of reading comprehension (e.g., identifying main ideas). Plato Focus provided a large database of resources including text passages, video clips, Internet sites and software modules. The programs were intended to supplement teachers' core curriculum. Thus, the impact of the technology was evaluated in the context of specific, and differing, core literacy curriculums (Crowe, Connor, & Petscher, 2009). The average cost for the technologies was about $100/student. Of note, the cohort 1 study was not designed to evaluate the effectiveness of individual software packages but rather the effect of access to and use of these packages as they might be implemented in schools across the nation. The cohort 2 study did examine programs individually.

The results of the cohort 1 study revealed that there were *no* significant differences between the treatment and control students on the Stanford Achievement Test (SAT-10) or on other measures of reading, including those administered by the schools.

In the second cohort study (Campuzano et al., 2009), the teachers (treatment and control) were followed for a second year using the same software but with a different cohort of students. The aim was to examine whether using the software for a second year would yield stronger reading outcomes and to investigate whether efficacy varied among software products. Six products were included (see Table 47.1); four in first grade and two in fourth. With regard to overall student outcomes, there were no differences in reading outcome effects for students in cohort two for either first or fourth grade compared to the control group. Nor did cohort 2 students achieve stronger reading skills compared to cohort 1 students who received the technology. Although the amount of time students used the software increased from year 1 to 2, the authors concluded that using the technology for a second year did not improve student outcomes. When the investigators examined the effect sizes (treatment vs. control) for the individual software packages for cohort 2, they found that only *LeapTrack* in fourth grade had a significant positive effect (normal curve equivalent difference between treatment and control = 1.97). None of the other technologies promoted students' reading scores compared to the control group students.

These are discouraging results, especially for those who are pro-technology, because it is difficult to find fault with the studies. They were adequately powered. Tested outcomes aligned with the goals of the software packages. Teachers within schools were randomly assigned, which helped to control school effects. The sample included schools in seven states and targeted schools that served children from lower income neighborhoods. Overall, the software programs were used in the way they were intended to be used by the publishers/developers. There were no clear biases. Teachers actually used the software and observations revealed that they made expected changes in their classroom practices.

One plausible reason for the generally null findings is that much of today's reading software does not provide instruction and practice in the areas that research indicates is important for students' mastery of key literacy skills. Santoro and Bishop (2010) reviewed over 20 reading software packages. They found that in general, many of the commercially available reading programs did not incorporate components of reading for which there was research evidence. Instead they focused on providing games and animation of illustrations. This would tend to take students' attention away from the text. Software with more engaging and user-friendly interfaces and that cost more tended to provide less research-based content. Thus popular software programs were likely to be less effective than less "flashy" researcher-developed interventions. Moreover, simpler supports for reading may be just as effective as or even more effective than computer games and other technology supports. For example, based on findings from an experiment they conducted, Smith and colleagues (Smith, Majchrzak, Hayes, & Drobisz, 2011) concluded that reading maps rather than playing computer games better supported 11 year olds comprehension of complex narrative text that required them to mentally model spatial situations.

Another possible reason for the national study findings is that the software might be more effective for some students and less effective for others. For example, Macaruso and colleagues (Macaruso, Hook, & McCabe, 2006) tested the efficacy of computer assisted instruction focused on improving students' ($n=179$) word recognition abilities. Two software packages, *Phonics Based Reading* and *Strategies for Older Students* (*SOS*) by Lexia Learning Systems (highly ranked in the Santoro & Bishop study) were used to supplement the literacy instruction students received in the classroom. Results mirrored the national evaluation study (Dynarski et al., 2007) and revealed that there were no differences in outcomes between students in classrooms that used the software and those in the control classrooms who did not. However, for students who were considered at risk for reading difficulties, using the software significantly increased gains in word decoding compared to students in control classrooms. Such aptitude-, or child-characteristic-by-treatment, interactions (Connor, 2011; Cronbach & Snow, 1977) suggest that extra time on the computer devoted to practicing skills that need to be strengthened might be particularly important for students who arrive in first grade with weaker reading skills but not for students already proficient in the targeted skills.

Despite the general findings of the national evaluation study (Campuzano et al., 2009; Dynarski et al., 2007), other studies of software interventions do find evidence that specific technologies can support students' developing reading skills. For example, Korat (2009) found that kindergarteners and first graders ($n=40$) who used e-books specifically designed using reading research findings demonstrated greater gains in vocabulary and word reading compared to a control group. The effect was larger for kindergarteners than for first graders. Another randomized control study comparing technology-intensive classroom learning activities at 25 rural public schools revealed that students in technology-intensive classrooms made greater gains in word reading (first grade) and comprehension (second grade) compared to students in control districts (Knezek, Christensen, & Knezek, 2008).

The studies examining *for whom* specific technologies are effective and for whom they are not indicate the importance of taking a more highly nuanced orientation to the question of whether technology works. In addition to the results reported above, there is accumulating research that indicates that technology may be particularly helpful for students who face learning challenges. For example, carefully designed e-books also supported improved reading skills for fourth graders who struggled with reading, with greater gains for students in the group that was able to control the animations (Ertern, 2010). Two computer-based interventions designed to improve attention skills, a critical executive function that is associated with reading skill development (McClelland et al., 2007), were effective in improving not only attention problems but reading fluency as well when students ($n=77$) were randomly assigned to either a control condition or one of two computer intervention programs (Rabiner, Murray, Skinner, & Malone, 2010). Notably, to be included in this study, students had to demonstrate attention difficulties.

Students with learning disabilities also face serious difficulties with writing (Graham, Harris, & Larsen, 2001). In a quasi-experiment, Englert and colleagues (Englert, Zhao, Dunsmore, Collins, & Wolberg, 2007) examined whether students using *TELE-web* ($n=35$) might demonstrate stronger writing skills compared to students who did not ($n=20$). All participating students had documented disabilities with the majority with reading disabilities. *TELE-web* is Internet-based software that is designed to provide support as students write expository essays, specifically for improving the structure and organization of essays by focusing on topic sentences, supporting evidence and detail, and concluding statements. Both groups of students accomplished the same writing tasks with the same general instruction except that the control group used paper and pencil. Overall, students using *TELE-web* were significantly more likely to write well-structured essays than were students using paper and pencil supports. However, these results should be interpreted with caution as there were a number of factors that might have contributed to the effects. For example, the researchers' had prior relationships with the *TELE-web* teachers, the overall quality of instruction was not assessed, there may have been unmeasured differences among students in the treatment and control conditions, and the nested structure of the data was not considered in determining treatment effects. Nevertheless, the promising results of the TELE-web technology call for additional research into its effectiveness.

Students who speak a language other than English also face serious difficulties understanding text, particularly with regard to vocabulary. In a quasi-experiment ($n=240$ students), Spanish-speaking fifth grade students learning English (English learners) who worked within a strategic digital reading environment called *ICON*, which stands for Improving Comprehension Online, demonstrated significantly greater vocabulary outcomes compared to students who did not use *ICON* (Proctor et al., 2011). There were, however, no significant differences in reading comprehension skills. Again, as with any quasi-experiment, causal inferences must be limited.

## Technologies for Reading to Learn

In our review of the literature, we found three technologies designed to support students' *reading to learn*. The three focus on different but critical skills: Text structure (Meyer et al., 2010), inference making (McNamara, O'Reilly, Best, & Ozuru, 2006), and summarizing (Caccamise, Franzke, Eckhoff, Kintsch, & Kintsch, 2007). All three of these skills are involved in creating a coherent and meaningful mental model of the information presented in text.

*Text structure: Intelligent Tutoring Structure Strategy.* The importance of text structure for comprehension has been demonstrated in several programs of research, particularly for comprehension (Meyer et al., 2002; Williams et al., 2005). In the Web-based Intelligent Tutoring Structure Strategy (ITSS), Meyer and colleagues (Meyer et al., 2010) have created a technology-based delivery system for teaching students to notice and identify text structure in expository passages. ITSS uses a software agent to teach students to identify the top-level structure of a passage by attending to signaling words and other cues to the organization. Once a structure is learned, students use the structure to write summaries and recalls of passages with which they are presented. ITSS includes an automated analysis system so that feedback on student selections and input is provided during instruction and practice. Meyer & colleagues (2010) examined the pre and post-test performance of fifth and seventh grade students using the ITSS. In this experiment, students within each grade level were randomly assigned to one of two versions of the ITSS: elaborated or simple feedback. They found improvements for both groups on immediate and 4-month delayed posttests on a variety of experimenter-designed measures that tapped the specific skills targeted by the ITSS. Only those in the elaborated feedback condition showed substantial improvement from pre to post test in comprehension as assessed with the Gray Silent Reading Test (GSRT).

Individualizing the ITSS lessons increased the effect on students' comprehension and knowledge of signaling devices in text (Meyer, Wijekumar, & Lin, 2011). Meyer compared a version of ITSS that individualized lesson sequence, difficulty of texts, and practice depending on students' online performance with the standard ITSS. Fifth grade students ($n=131$) were randomly assigned to the standard ITSS or individualized ITSS condition. Comprehension improvements on the GSRT were obtained for both groups but were larger in the individualized ITSS condition. A similar pattern was found on a signaling task that required students to identify cues in the text to its structure. Free recall improved from pre to post for students in both conditions but there was no differential effect of individualization. What is not clear is how using the ITSS might compare to a non-technology business-as-usual condition.

*Tutoring inferences: iSTART. iSTART* (Interactive Strategy Trainer for Active Reading and Thinking) is an automated intelligent tutoring system that is designed to assist readers in making appropriate inferences as they are reading, particularly those that support deep comprehension as opposed to literal or rote memorization of text. Most widely deployed and tested for science content (McNamara et al., 2006). it was developed to help students improve their ability to read for understanding by constructing self-explanations of text using five strategies for making inferential connections among elements of text and to prior knowledge (McNamara et al., 2006): paraphrasing (to insure accurate comprehension of what the text says); bridging, elaborative, and predictive inferences; and comprehension monitoring. Results of a randomized control trial with 39 seventh and eighth graders revealed that on a post-training text, students in the iSTART condition comprehended more than did the students in the control condition (strategies were defined but no technology was provided). This study also provided evidence that the impact of iSTART differed depending on the pretraining knowledge students in the iSTART condition had of reading strategies. Those with higher knowledge showed greater achievement on inference questions as compared to literal whereas lower strategy knowledge students achieved more on literal than inference questions. As with several other technologies for supporting reading, the impact of iSTART depended on the characteristics of the individual reader. Additionally, the sample was small so it is not clear how iSTART will work with different student populations.

*Summarization: Guided practice with feedback. Summary Street* is a Web-based system for middle and high-school students that provides guided practice in writing summaries for presented passages. The feedback is provided in the form of suggestions for improving the summary and students then decide what actions to take to improve their summaries. They are free to ignore or act on any of the feedback at their discretion. This "intermediate" level of feedback is consistent with other studies of tutors and tutoring that suggest that the most useful feedback allows the user some agency in determining what to do next (Aleven & Koedinger, 2002; Chi, Siler, Jeong, Yamauchi, & Hausmann, 2001). The feedback utilizes a back-end computational process that relies on latent semantic analysis to determine similarity between the summary generated by the student and the text that the student is summarizing (Wade-Stein & Kintsch, 2004). Sixth through ninth grade students from a variety of socioeconomic backgrounds across the state of Colorado participated in a quasi-experimental study (Caccamise et al., 2007, 2010). Treatment classes ($n=80$ students) used the *Summary Street* software while control classes ($n=60$ students) matched to each treatment classroom did not. At the beginning and end of the semester, students wrote a summary (paper and pencil) whose quality was evaluated by the *Summary Street* system. Results indicated that treatment group students' summaries showed significant improvement in content coverage (more relevant, less redundancy, more parts of the text) whereas those of the control students did not (effect size $d=0.67$). A 2-year evaluation study revealed an effect size ($d$) of 0.26 when quality of summaries produced by *Summary Street* users was compared to those in the control condition. Study findings for four eighth grade classes indicated that the feedback was strongly associated with improvement in summary writing and gist-level reading comprehension (Franzke, Kintsch, Caccamise, Johnson, & Dooley, 2005). Furthermore, the effects of the feedback on summary writing were greater on more difficult texts and for students who scored lower on a comprehension assessment.

## Technology and Assessment

The most recent National Education Technology Plan (NETP, US Department of Education, 2010) focuses on the role of technology for providing better ways to measure what is important for students to learn if they are to successfully navigate information in our global society. This includes diagnosing students' strengths and weaknesses *as* they are learning, using automated scoring to evaluate student writing, providing timely and actionable feedback to teachers and students, and building the capacity of educators to use this technology.

### Evaluating Student Writing

*Constructed responses.* In general, cognitive and educational research findings concur that students learn better and we can make better judgments about their achievement when they are presented with open-ended questions that require constructed responses, including short answer and essays (Bennett & Ward, 1993). Moreover, one likely reason that there is limited research on how children master proficient writing is that the constructed responses and other forms of written products are difficult and time consuming to reliably assess. New automated essay scoring systems offer potentially important solutions to these concerns. These systems use a number of strategies to evaluate the quality of written text. A widely used and validated technology is the e-rater v.2 (Attali & Burstein, 2006). *E-rater* examines "grammar usage, mechanics, style, organization, development, lexical complexity, and prompt-specific vocabulary usage" (p. 7). When e-rater scores were compared with human rater scores for essays generated by 6th through 12th graders, in general, e-rater agreed with the human raters at the same rates as the human raters agreed with each other with kappas ranging from 0.31 to 0.44 for computer–human agreement and from 0.27 to 0.44 for human–human agreement (Attali & Burstein, 2006). Hutchinson (2006) replicated this finding with younger students (11 year olds, $n=600$) in the UK.

In order to take advantage of automatic essay scoring systems, students will likely be expected to complete their essays on computers. A study by Horkay and colleagues (Horkay, Bennett, Allen, Kaplan, & Yan, 2006) examined whether students ($n=1{,}313$) achieved significantly different scores when taking the writing portion of the National Assessment of Educational Progress (NAEP, 2011) online (keyboarding) or with paper and pencil. Results revealed that overall, mode (online or paper) made no significant difference in achieved score. Nor did any of the student or school factors interact with mode with one important exception: Students who had weaker keyboarding skills achieved higher scores when they completed the essays using paper and pencil whereas students with proficient keyboarding skills achieved higher scores when composing their essay online. This offers a cautionary note because not all students have the same access to computers and training in keyboarding.

*Formative assessments.* Accumulating research strongly indicates that formative assessments, those assessments used to inform the types of instruction and interventions that will better support students' learning, are an integral part of an effective instructional regimen (Deno et al., 2002; Pellegrino, Chudowsky, & Glaser, 2001). Formative assessments differ from summative ones such as the NAEP and state-mandated assessments. The latter are useful in understanding students' achievement relative to a normative group. However, they are less useful when teachers are planning and implementing instruction because of their distance from the actual curriculum and instruction in the classroom. Assessments are considered to be formative insofar as the information gained from these assessments is used to make decisions about what to teach students (i.e., content) and how to teach it (e.g., strategies, directly, implicitly). Technology can facilitate both the administration and scoring of such assessments and thereby make it more likely that teachers will be better able to differentiate instruction appropriately so that individual students' needs are more effectively addressed. For example, Sainsbury and Benton (2011) used latent class analysis to identify four different profiles of learners based on two formative reading assessments. They conjectured that the four different profiles would benefit from different types of reading instruction although this was not tested. In another example of online formative assessment. Connor and colleagues have developed an adaptive vocabulary or word knowledge assessment for kindergarten through fifth grade, *The Word Match Game*, using a semantic matching task (Connor, 2011). Over headphones, students are presented three words (e.g., kitten, cat, tree) and are asked to click the two that go together (e.g., kitten, cat). The task is adaptive, using item difficulty information (Petscher et al., 2012), so the number of items administered is substantially less than might be needed for paper and pencil assessments. Importantly, the results of these formative assessments can be used immediately to help teachers design and implement effective literacy instruction. And they can be administered fairly frequently to monitor whether or not students are improving their skills as expected.

Overall, computer-based assessments have several advantages over paper and pencil. Automatic scoring and use of psychometric information means that the results of the assessments can be presented as grade equivalents, standard scores, and developmental scale scores to monitor gains in skills and knowledge over time. Awkward look-up tables are avoided and data entry and scoring mistakes are minimized. Importantly, scores are available to teachers immediately and can be presented graphically in a number of ways to aid interpretation of the results.

## Assessing Multiple Source Comprehension

Technology, specifically the World Wide Web, has expanded the range of available resources for reading to learn, and in multiple formats, including text, audio, and visual. More so than ever before, readers are likely to come across sources that make contradictory claims and offer different evidence, or different interpretations of evidence, in support of those claims. The result is that the skill set for reading to learn has expanded to include reading skills that had previously been purview of subject-matter experts only (Goldman, in press). One tool for assisting teachers in making the transition to reading and writing from multiple sources of information is to create formative assessments that assess the skills required to select and use information from multiple sources. Goldman, Lawless and colleagues (Goldman et al., 2010, 2011, 2012; Lawless, Goldman, Gomez, Manning, & Braasch, in press) have developed Web-based formative assessments of two important skills in learning from multiple sources: selecting sources and synthesis of information across sources. Both assessments are designed to provide teachers with information about middle school students' skills at selecting relevant and reliable sources and integrating across them to address inquiry questions in history or science (e.g., "Why did so many people move to Chicago between 1830 and 1930?", p. 19, Goldman et al., 2012).

The *Selecting Sources Assessment* defines useful sources as those that are relevant and reliable (translated as trustworthy for the 5th-8th grade target population). In this task, students evaluate eight different sources with regard to their *relevance* to answering the question, and for those deemed relevant, the *trustworthiness* of the source. Overall usefulness is determined by rank ordering those sources that survive the relevance and trustworthiness judgments. In the online, computer-based context, judgments are made on a three-point Likert scale for relevance and trustworthiness (1 = highly; 2 = somewhat; 3 = not). For trustworthiness ratings, students rate how helpful to the trustworthy judgment each of four attributes of the source are (author, type, publication date, and publication venue) and make an overall trustworthiness judgment. Usefulness is determined by rank ordering using prize ribbons (first place, second place, and so on) to those sources ranked a 1 or 2 for both relevance and trustworthiness.

Across several studies with 5th through 8th graders, results revealed a wide range of performance. In general, students who performed at higher levels as compared to those performing at lower levels on the usefulness ranking task also performed at higher levels on the relevance judgment task; however, performance on trustworthiness judgments did not differ significantly. Moreover, evidence suggested that these tasks were tapping skills and knowledge not generally captured by more traditional reading comprehension tests.

The assessment tool for *Analysis and Synthesis* across sources asked students to read three texts for purposes of answering an inquiry question. After reading, they were asked to type an answer to the inquiry question using the information from the texts. Specifically they were told, "the answer comes from many sources and you have to fit the reasons you find together like pieces in a jigsaw puzzle to answer the question" (p. 192, Goldman et al., 2012). They clicked on tabs at the bottom of the screen to bring up each text; all three could be accessed in any sequence, any number of times but only one text appeared on the screen at a time. After reading the texts, students typed their responses, and could re-access the texts. The Computer recorded the timing and sequence of which texts were viewed.

The students' essays were scored for inclusion in their essays of information from each of the three texts (analysis) as well as for the degree to which they connected information across the three texts (for details see Goldman et al., 2012). Results across samples of 5th through 8th graders ($n = 247$) revealed that there were three distinct ways in which students completed the task. The *satisficers* (50 % of the students) wrote the shortest essays with the least amount of information, spent the least amount of time writing, and did not relate content across texts. The *selectors* (36 %) wrote the longest essays and spent the most time writing, although they tended to copy sentences directly from the texts. Although 77% of the students included information from all three texts, they did not connect information across texts. The *synthesizers* (13%) connected information across at least 2 texts with the majority, 77%, using all three texts and the information selected tended to be the more important and relevant information from each text.

## Technology to Support Teacher Learning and Effective Practice

One of the most promising uses of technology is to support teachers' efforts to provide effective literacy instruction. This includes professional development to increase knowledge about effective practices and how to use assessment results to guide instruction. We discuss recent research in both of these areas.

### Technology and Teacher Professional Development

Research on professional development has shown that, in general, a combination of workshops, monthly teacher meetings focused on building communities of practice, and classroom-based coaching are most likely to change teachers' practices (Carlisle, Cortina, & Katz, in press). However, such professional development is costly, especially in more rural districts where travel time is a consideration. Several recent studies indicate that online professional development and other technologies hold promise for providing cost-effective ways to improve teachers' literacy practices. For example, Hemmeter, Snyder and colleagues (Hemmeter et al., 2011) found improvements in preschool teachers' interactions with students and improved student behavior when feedback was provided to teachers via email and using teacher-selected video tapes of their instruction. Amendum, and colleagues (Amendum, Vernon-Feagons, & Ginsberg, 2011) provided *Targeted Reading Intervention* professional development to teachers at randomly assigned schools ($n = 364$ students) using Web conferencing, laptop computers, and webcam technology. Results indicated that the professional development was effective and the reading skills of students who were struggling with reading improved compared to students in the control group. Furthermore, Powell and colleagues conducted a randomized control study revealing that technology-based coaching might be as effective as face-to-face coaching (Powell, Diamond, Burchinal, & Koehler, 2010) for Head Start teachers ($n = 88$). Both treatment groups were more effective than the control group.

In another study, Landry and colleagues (Landry, Antony, Swank, & Monseque-Bailey, 2010) evaluated the effect of four different configurations of professional development compared to a control group. Preschool teachers ($n = 262$) from four different states were randomly assigned to a business as usual control or to one of four PD conditions that provided different combinations of: weekly literacy coach mentoring, paper and pencil assessment, and personal digital device assisted assessment (C-PALLS), and no mentoring. All treatment group teachers participated in a year-long online course called *eCIRCLE*. *C-PALLS* used the same assessments as paper-and-pencil versions but administration was facilitated and scoring and data displays were generated automatically so teacher received immediate feedback. Results showed that teachers in all four treatment conditions improved the quality of their early literacy instruction compared to the control group teachers. Overall, however, teachers who used *C-PALLS* (particularly with mentoring) tended to be rated as highest on the scale and their students made significantly greater gains in early literacy and oral language skills compared to the control and other conditions.

### Technology Designed to Help Teachers Use Assessment to Guide Instruction

Accumulating evidence shows that the effect of a particular instructional strategy depends on the vocabulary and reading skill level of the student. This phenomenon has been identified as child characteristic-by-instruction type (child-by-instruction) interactions (Connor, Morrison, & Petrella, 2004), individual response to intervention (Torgesen, 2000) and aptitude-by-treatment interactions (Cronbach & Snow, 1969). Recent randomized control field trials have provided evidence that such child-by-instruction interactions are causally related to the widely varying levels of student achievement observed within and between classrooms and schools from kindergarten through third grade (Connor et al., 2009; Connor, Morrison, Fishman, Schatschneider, & Underwood, 2007). Thus patterns of instruction that are effective for one child may be ineffective for another who shares the classroom but has different oral language and literacy skills. As we discussed, this seems to be the case for computer-based interventions as well (MacArthur et al., 2001). However, differentiating instruction in line with these child-by-instruction interactions is highly complex and demands skills and knowledge that many classroom teachers lack (Roehrig, Duggar, Moats, Glover, & Mincey, 2008).

Assessment-to-Instruction (A2i) online software was designed to help teachers translate assessment results into specific recommendations for literacy instruction. Part of a classroom-based intervention called Individualizing Student Instruction (ISI), which includes professional development, A2i software has four components: (1) assessment and recommended instruction; (2) planning; (3) professional development; and (4) teacher communications. Teachers use the software, which is indexed to their core reading curriculum, to plan daily instruction and monitor students' progress. They have access to online training materials, including videos and discussion boards that provide information about effective instruction, organizing and planning, and classroom management. Importantly, computer algorithms provide specific recommendations for the amount and type of reading instruction that will be optimal for each student, based on the assessment results.

From kindergarten through third grade, students' whose teachers were randomly assigned to the ISI intervention (i.e., differentiated instruction) using A2i made greater gains compared to students whose teachers were in the alternative or delayed treatment control groups (Connor et al., 2007; Connor, Carol McDonald, Morrison, & Frederick et al., 2011; Connor, Morrison, Schatschneider et al., 2011). Focusing only on first grade teachers who used A2i ($n=25$), Connor and colleagues found that the more teachers used A2i, the greater were their students' ($n=396$) reading skill gains (Connor, Morrison, Fishman, & Schatschneider, 2011). This finding was replicated in third grade with 16 teachers and 226 third graders (Connor, Fishman et al., 2011).

In a direct test of A2i, Al Otaiba and colleagues (Al Otaiba et al., in press) compared student outcomes ($n=556$) for kindergarteners whose teachers were randomly assigned to receive professional development (PD) on how to differentiate reading instruction ($n=21$ teachers) but no technology or whose teachers ($n=23$) were assigned to receive professional development on differentiating instruction using A2i (i.e., with technology). They found that teachers were more likely to individualize instruction and their kindergartners made greater gains in reading when they used the A2i technology compared to the PD-only group teachers.

## Discussion

Our review of the most current research on reading and writing technology is highly encouraging. Accumulating research shows that carefully designed software can support students' emergent literacy development, improve foundational reading skills as students learn to read, and can offer opportunities to improve their ability to use their developing literacy skills to learn from text, particularly in the content areas. Furthermore, when these technologies individualize the material based on students' skills and abilities, the impact tends to be larger than in the absence of this differentiation. Computer- and Internet-based reading and writing assessments make evaluation of student work easier, faster, and more reliable. They allow us to assess and monitor more complex twenty-first century literacy skills such as evaluating the relevance and trustworthiness of text for the topic at hand. Technology is facilitating professional development efforts and making training more available to teachers in more places. Moreover, technology is helping teachers individualize the literacy instruction they provide to their students by facilitating the use of assessment information to design, plan, and implement effective differentiated instruction.

There are some important caveats, however. Technology is good at some things and not others. For example, accumulating evidence clearly indicates that technology is not going to replace good teaching—or even typical teaching—given the current state of the art. This is exemplified by the national evaluation study (Campuzano et al., 2009) where the overarching albeit implicit research question was: can school districts, particularly those who serve many students from higher poverty families, buy technology and achieve stronger student achievement? In other words, can putting students on computers to replace face-to-face instruction from teachers lead to better student outcomes? The answer was a clear "no." This is good to know and allows us to more honestly evaluate the nuanced role of reading and writing technology. For example, in the national evaluation study, software developers encouraged teachers to become "guides on the side" rather than the "sage on the stage." And classroom observation revealed that, indeed, teachers in the technology groups were more likely to act as guides than were teachers in the control group. However, this begs the question as to whether this is the best use of teachers' classroom time. Although conjecture, might the results have been different if teachers integrated the software into their classroom instruction rather than treating the software as an add-on for the computer lab. What if some of the students had worked with technology-based activities in the classroom while their teacher worked directly with other students, perhaps those who needed small group or one-on-one attention? The key finding from several of the studies we reviewed (e.g., Connor, 2011; Macaruso et al., 2006) was that the impact of the technology or instructional strategy depended on students' incoming reading and language skills *and* whether the instruction specifically targeted those areas in which students' understanding and skills were weaker. For example, technology used to provide students who are struggling to learn to read with extra practice time on the computer with, say an e-book that helps them sound out unfamiliar words and has a dictionary, rather than expecting them to read independently is likely to help them improve their skills. At the same time, for more skilled first graders to spend time on the computer working on basic skills they have already mastered is likely a waste of their instructional time. These students would probably be better served by spending that time reading and writing independently (Connor, Morrison, Schatschneider et al., 2011). The one software package in the national evaluation study (cohort 2, Campuzano et al., 2009) that did appear to promote student learning, *LeapTrack* in fourth grade, described itself as a "personal learning tool" for students (see Table 47.1) and incorporated assessments to place students in e-books that were at the appropriate level for them. It also recorded how well students performed and provided assessment reports. Moreover, *LeapTrack* in fourth grade incorporated research findings on effective decoding and comprehension instruction and was designed to be used in the classroom rather than the computer lab.

Despite accumulating evidence that students are better served when teachers differentiate instruction, individualized instruction is not happening in many schools (Black & Wiliam, 2009; O'Connor, Fulmer, Harry, & Bell, 2005). Technology can assist with this in several ways: first, by providing sensitive, meaningful, and more nuanced formative assessment of skills that truly matter; second, by supporting teachers' efforts to use that assessment information in meaningful ways to plan and implement literacy instruction; third, by freeing up time currently spent on assessment to provide effective instruction particularly on skills that are difficult to teach using technology; and finally, to provide a digital support system or intelligent tutor for students, including students with disabilities, as they work on their own while the teacher works directly with other students. The NETP (US Department of Education, 2010) directly calls for this, stating:

> The model of learning described in this plan calls for engaging and empowering learning experiences for all learners. The model asks that we focus what and how we teach to match what people need to know, how they learn, where and when they will learn, and who needs to learn. It brings state-of-the art technology into learning to enable, motivate, and inspire all students, regardless of background, languages, or disabilities, to achieve. It leverages the power of technology to provide personalized learning and to enable continuous and lifelong learning (p. 8).

For all of this to happen, however, innovative design and rigorous testing of software is required. We were encouraged by the number of well-crafted randomized control and quasi-experimental studies (we carefully reviewed over 80 studies and of these, about 25 met our standards for inclusion in this review; we reviewed over 500 titles and abstracts). At the same time, given budget constraints, funding priorities, and popular support, there is a danger that emerging technologies will go straight into classrooms and schools without strong evidence that using the technology will improve student learning. By understanding how the technology works, in what contexts, and for whom, we can more effectively and efficiently employ school, teacher, and student resources to insure all students receive the instruction they require to succeed.

**Acknowledgments** We would like to thank Callie W. Little, Florida State University, for her assistance with searching data bases and Web sites, as well as for her preliminary review of journal articles. The writing of this chapter was supported in part by the US Department of Education, Institute of Education Sciences, Reading for Understanding grants R305F1000027 and R305F100007; and Assessment development grant R305G050091, grant R305B070074 Child by Instruction Interactions: Effects of Individualizing Instruction, and by grant R01HD48539 from the National Institute of Child Health and Human Development. The opinions expressed are those of the authors and do not represent the views of our institutions or the funding agencies.

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