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Educational Technologies that Support Reading Comprehension for Adults Who Have Low Literacy Skills

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Abstract

Digital technologies are playing an increasingly important role in helping adults with low literacy improve their reading skills. Whereas there is an abundance of technologies designed to improve basic reading skills (such as word decoding, letter sound correspondence, vocabulary), there are fewer technologies to help adults improve reading comprehension (such as sentence meaning, inferences, text cohesion, discourse structure) and use digital media. This chapter focuses on the technologies that target comprehension strategies for adults with low literacy skills. We propose that it is important to ground the technologies in science and practice by aligning: (1) multilevel theoretical frameworks of comprehension, (2) interventions to improve comprehension, (3) reading curriculum standards, (4) assessments of comprehension, and (5) text characteristics. One type of technology to provide comprehension instruction for low literacy adults are those with conversational agents (talking heads, avatars) because they provide oral communication and help the adults apply comprehension strategies to texts and navigate the digital technologies. Some technologies address motivational variables, such as independent reading and the selection of documents that consider adult interests, vocations, and practical value in the digital age of the 21st Century.

Keywords: AutoTutor, comprehension, cohesion, independent reading, inferences, multilevel theoretical framework, rhetorical structure, text difficulty

Educational Technologies that Support Reading Comprehension for Adults Who Have Low Literacy Skills

This chapter describes some technologies that have been developed to help adults who have low literacy skills improve their reading comprehension. The primary focus is on deeper levels of comprehension, including sentence comprehension, inferences, text cohesion, and rhetorical structures in different types of discourse: narrative, persuasive, and informational texts, as well as forms and digital media. Digital technologies are expected to play an important role in improving adult comprehension for at least three reasons. First, there is a greater reliance on technology in contemporary society so it is important to take stock of the potential of technology for improving comprehension. Second, instructors in literacy centers have less experience and training on teaching comprehension strategies compared with their covering basic level reading skills, such as letter-sound correspondence, word decoding, morphology, and vocabulary. Consequently, the technology is a promising approach to improve comprehension instruction for professional development as well as helping adults with low literacy skills (hereafter called *adult learners*). Third, many of the technologies are available to adult learners whenever they have the time and inclination to concentrate on comprehension instruction, whereas access to human instructors is more constrained in time and spatial proximity.

This chapter has four major sections. The first section describes the role of digital technologies in the lives of adult learners, in comprehension instruction, and in professional development. The second section discusses an approach that aligns technologies with theoretical levels of language and discourse, pedagogically effective instruction, curriculum standards, assessment, and text characteristics. This alignment approach has been adopted by the Center for the Study of Adult Literacy (CSAL, csal.gsu.edu), a national reading research center (funded by

the Institute of Education Sciences, U.S. Department of Education) that focuses on adults who read between the 3.0 and 7.9 grade equivalency levels. The third section describes technologies with conversational agents (talking heads, avatars) that target comprehension instruction and digital media. For example, *AutoTutor* is a web-based instructional tutor (Graesser, Cai et al., 2016) that has two computer agents (talking heads) that hold a conversation with the adult learners and with each other. The AutoTutor agents guide the adult learner in implementing reading comprehension strategies (e.g., clarifying pronouns, identifying main ideas, understanding compare-contract structures) and also navigating the computer environment. AutoTutor's comprehension strategies are aligned with a face-to-face intervention that teachers have successfully implemented to improve reading comprehension in middle and high school students with reading difficulties (Lovett, Lacerenza, De Palma, & Frijters, 2012). The fourth section describes digital technologies that analyze the content of reading materials so that readers can read texts that match their abilities and interests. Systems have been developed that scale texts on difficulty with respect to multiple levels of language and discourse by analyzing characteristics of words, syntax, discourse cohesion and text category (McNamara, Graesser, McCarthy, & Cai, 2014; Nelson, Perfetti, D. Liben, & M. Liben, 2011). The chapter concludes with some recommendations for future research.

It is important to clarify the scope of this chapter because the literature on educational technologies is extensive and rapidly changing. Given the theme of this edited volume, the focus is on technologies that target adult learners rather than K12 and proficient adult readers. As already mentioned, we concentrate on training comprehension rather than basic reading processes. There are substantially more digital technologies for basic reading processes than comprehension training, undoubtedly because it is generally more difficult to train and scaffold

comprehension strategies (for coverage of digital comprehension trainers, see McNamara, 2007; Crossley & McNamara, 2016). There are very few digital comprehension trainers for adult learners because digital instructional technologies have only recently penetrated this population. In summary, this chapter provides a snapshot of the research on digital technologies that provide comprehension training for adult learners.

The State of Digital Technologies in Adult Literacy

Computer use is ubiquitous in today's societies. Adults need to use computers to fill out forms, receive benefits, and enroll in health care, work place, and educational programs. In an international survey, it was found that literacy skills and frequency of computer use are positively related to the ability to use the computer to complete tasks (OECD, 2013, 2015). That is, both literacy skills and one's ability to use computers are related to one's success in being hired in relatively higher paying jobs (Carnevale & Smith, 2013; OECD, 2015). It is therefore important to increase both reading skills and practice in using computers to complete tasks.

As Elish-Piper (2007) points out, the adult literacy population is particularly heterogeneous in most defining characteristics, such as age, race/ethnicity, country of origin, highest educational level attained, literacy skills, interests, and goals. Population diversity increases the difficulty of the instructor to optimize learning in groups or classrooms of students, even when there are attempts to differentiate instruction among subgroups. A computer program, on the other hand, can get closer to this optimal level by adapting instruction to the individual learner based on the learner's responses to tasks (Fletcher, 2003; Graesser, Rus, & Hu, 2017; Woolf, 2009). Moreover, consistent program attendance is a problem in adult literacy due to unstable work hours, transportation difficulties, and childcare issues (Alamprese, MacArthur, Price, & Knight, 2011; Greenberg, 2008; Greenberg et al., 2011; Hock & Mellard, 2011; Miller,

Esposito, & McCardle, 2011; Sabatini, Shore, Holtzman, & Scarborough, 2011). Being able to access a computer program on the Internet is an excellent way for absent adult learners to continue to work on literacy skills. It is promising that 85% of respondents from over 1000 programs believe that technology can benefit adult education (Newnan, 2015) and that adult literacy learners are very interested in learning how to use technology to increase their skills and to help them navigate daily tasks (Pendell, Withers, Castek, & Reder, 2013).

The question arises as to whether it is realistic to develop digital technologies for adult literacy instruction. There are reasons to be encouraged. Between 2001 and 2002, 1200 federally funded adult literacy programs were surveyed, and results indicated that 80% of the programs used computers in some type of capacity with adult learners (Tamassia, Lennon, Yamamoto, & Kirsch, 2007). Due to the growth in computer usage, it is assumed that this number is even higher today. According to the 2003 National Assessment of Adult Literacy (Kutner et al., 2007), the 67% of adults who read at grade levels 3 to 7.9 had a computer in their home with Internet access. The percentage is even higher in the more recent survey of PIAAC, the Programme for International Assessment of Adult Competencies (OECD, 2015). Computers with Internet access are also available for adult learners in public libraries, children's schools, and adult literacy programs. Newnan's (2015) survey of more than 1000 programs indicated that more than 80% of survey respondents had computers in their classrooms with consistent access to the Internet (although significant variability was noted). Peterson (2016) reported that an increasing number of adult literacy programs are infusing technology into their classrooms and curriculum.

On the other hand, there are challenges to overcome. Most reading instructional programs are not designed for adult literacy students because K12 has had higher priority (Newnan, 2015).

Technological programs geared for adult learners must not only focus on adult content, but they need to (a) be understood easily by adult learners, (b) include scaffolding to help them use the technology, (c) be comparatively short in duration, (d) consider the program's instructors, and (e) accommodate the learners' highly variable Internet and wireless connectivity. Integrating digital technologies into instruction for adult learners has traditionally been minimal or absent in major programs for the professional development of teachers and tutors of adult literacy. For example, the *STudent Achievement in Reading* (STAR) program of the Office of Career, Technical, and Adult Education (OCTAE) under the U.S. Department of Education (https://lincs.ed.gov/programs/studentachievementinreading) trains instructors on basic reading skills and comprehension strategies, but does not weave in digital technologies in the professional development.

As noted by Peterson (2016), the tides are beginning to change in incorporating digital technologies in instructional systems for both professional development and adult learners. *ProLiteracy* (www.proliteracy.org) and the *American Library Association* (www.ala.org) have recently teamed together to help literacy providers, librarians, and library workers deliver innovative literacy services, including those with digital technologies. *USA Learns* (www.usalearns.org) provides free on-line training of speaking, listening, reading, and writing, but covers basic reading processes rather than comprehension training. The *CASA Academy* is developing a reading test series that is aligned with the College and Career Readiness (CCR) Standards for Adult Education and gives students practice with CASAS items (www.casas.org). On-line test preparation is also provided commercially by several companies. The *California Adult Education Courses* (www.adultedcourses.org) provides on-line access to several adult education courses in different locations in California. These organizations have taken important

steps in giving adult learners web access to reading materials, diagnostic tests, practice completing tests, and instruction for various reading skills. Unfortunately, these resources require that the adults have sufficient digital literacy to use the web sites. Another limitation is that the instruction on comprehension does not differentiate specific comprehension strategies and components.

The digital divide is exacerbated by many adults' poor digital literacy skills (Peterson, 2016). For example, according to the PIAAC, only 31% of adults in the United States exhibited basic proficiency in problem solving in technology rich environments (OECD, 2013). The Pew Research Center reported that 52% of adults are "relatively hesitant" in using technology for learning, with 14% of these individuals completely unprepared in using technology (Horrigan, 2016).

Olney, Bakhtiari, Greenberg, and Graesser (2017) recently tested 114 adult learners on a customized NorthStar Digital Literacy Assessment (NDLA; www.digitalliteracyassessment.org) that was developed by the St. Paul Community Literacy Consortium (2014). The NDLA is an online behavioral test of computer literacy skills. As a behavioral test, the NDLA presents tasks that the user must complete in a simulated computer interface. For example, if the task is to drag a file to the Recycle Bin, the user must actually click and drag a file in the simulated interface and then release the file over the Recycle Bin. The NDLA consists of self-contained modules addressing various types of computer skill. Tasks in the Olney et al. (2017) were selected from four different NDLA modules: Basic Computer Skills (21 items), World Wide Web (13 items), Windows (6 items), and Email (4 items). The resulting 44 items were administered to 114 adults who read between the 3rd and 8th grade level. These same adults also completed a computer

familiarity self-report questionnaire (csal.gsu.edu) that included self-report questions about their frequency of computer use and computer habits.

The advantage of a behavioral test is demonstrated by comparing its results to the self-report measure. While 72% of the adult learners reported using a computer for five or more years and 36% reported using a computer at work, only 24% could demonstrate on the NDLA the correct use of the Enter key to start typing on a new line. The percentage of adults who could perform NDLA tasks correctly ranged from 20% to 96%. The four tasks in which the adults were most proficient (> 90% correct) were identifying a mouse, keyboard, headphone jack, and recycling documents via drag and drop. Most of the adults could click on a hyperlink. The four tasks in which the adults were least proficient (< 30% correct) involved right clicking, typing, and knowledge of different web browsers. The majority of these adults were not able to complete simple tasks such as opening a Word document in a taskbar, typing in a web address and clicking NEXT, or choosing a secure password and typing it in a "re-enter password" box.

Conversational agents provide one solution to handling limited digital literacies of adult readers. Conversational agents are talking heads or avatars that speak to the adult with recorded human voices or synthetic text-to-speech facilities. The agents can give instructions to the learners when they have trouble using important features on the computer interface. When properly designed, these agent technologies can provide support that is analogous to a human teacher or tutor.

At the time this chapter was written, there were three systems that had conversational agents for training adult learners comprehension strategies. The primary system that is discussed in this chapter is *AutoTutor* (Graesser, 2016; Graesser, Cai et al., 2016), which is covered in a subsequent section. The AutoTutor agents guide the adult in navigating the computer screens in

addition to training them on dozens of specific comprehension strategies. AutoTutor is adaptive to the learner's performance and abilities rather than being rigidly scripted lectures. *Essential Education* (www.essentialed.com) of the GED Academy also teaches comprehension with an agent that has pre-recorded voices, but it is rigidly scripted rather than being adaptive to the learner's performance and abilities. The third system with agents is *iSTART* (interactive Strategy Training for Active Reading and Thinking). The iSTART system was originally designed to improve comprehension strategy training for students in middle school, high school, and college (Jackson & McNamara, 2013; McNamara, O'Reilly, Rowe, Boonthum, & Levinstein, 2007), but a version was recently developed for low literacy adult readers (Johnson, Guerrero, Tighe, & Danielle, 2017). The iSTART system is adaptive and focuses on specific comprehension strategies, particularly those that involve explaining the meaning of ideas and constituents explicitly mentioned in the texts. The adult learners are required to provide written responses in iSTART whereas the students in AutoTutor do not type in information, except for a small number of lessons in which they occasionally type in a word or phrase. Given that writning is a challenge for most low literacy adults (Olney et al., 2017, Perin, 2013), AutoTutor is appropriate for the majority of adult learners. In contrast, adults who can type in sentences and paragraphs would presumably best be assigned iSTART. However, there have been no empirical tests of adult subgroups that benefit most from comprehension training provided by AutoTutor, iSTART, Essential Education, versus other digital technologies.

Whatever digital training of comprehension that is provided for low literacy adults, it is important to consider the principles of learning that guide the design of the technology. Learning technologies are destined to fail without a systematic plan for the design and testing of the artifacts. The next section describes an alignment approach to guide the design plans.

Alignments among Technologies, Theory, Curricula, Assessments, Standards, and Texts

Technologies that are developed to improve reading comprehension strategies are ideally designed with explicit alignments with different strands: theory, curriculum, educational standards, assessments, and text characteristics. Indeed, alignment is presumably needed across all of these strands, which was a principle explicitly followed in the CSAL research agenda and the design of AutoTutor. This section starts with theory and then identifies relevant alignments with components of the other strands.

Theoretical frameworks with multiple components and levels

Theoretical models of comprehension typically adopt a multicomponent, multilevel framework (Graesser & McNamara, 2011; Kintsch, 1998; Perfetti, 1999). For example, the Graesser and McNamara (2011) framework identifies six levels: *words*, *syntax*, the explicit *textbase*, the referential *situation model* (sometimes called the mental model), the discourse *genre and rhetorical structure* (the type of discourse and its composition), and the *pragmatic communication* level (between speaker and listener, or writer and reader). Words and sentence syntax are straightforward, but the other four levels merit some clarification.

***Textbase*.** The textbase consists of the explicit ideas in the text that preserves the meaning but not the precise wording and syntax. There are basic idea units, or what some people call statements, clauses, or propositions. *Co-reference* is an important linguistic method of connecting these explicit idea units in the textbase (Halliday & Hasan, 1976). Referential cohesion occurs when a noun, pronoun, or noun-phrase refers to another constituent in the text. A referential cohesion gap occurs when the words in a sentence or clause do not connect to other sentences in the text. Cohesion gaps at the textbase level increase reading time **(**Haberlandt &

Graesser, 1985; Just & Carpenter, 1987) and sometimes disrupt comprehension (McNamara & Kintsch, 1996; McNamara et al., 2010**).**

Situation model. The situation model is the subject matter content that the text is describing. In narrative text, this includes the characters, objects, spatial settings, actions, events, processes, plans, thoughts and emotions of characters, and other details about the story. In informational text, the situation model corresponds to the substantive subject matter (i.e., domain knowledge, topics) that the text describes. The situation model includes inferences that are activated by the explicit text and encoded in the meaning representation (Graesser et al., 1994; Kintsch, 1998; Van den Broek et al., 2009). Zwaan and Radvansky (1998) proposed five dimensions of the situational model that apply to the thread of discourse comprehension: causation, intentionality (goals), time, space, and people. A break in situation model cohesion occurs when there is a discontinuity on one or more of these situation model dimensions. Such cohesion breaks result in an increase in reading time and generation of inferences **(**O'Brien, Rizzella, Albrecht, & Halleran, 1998; Rapp, van den Broek, McMaster, Kendeou, & Espin, 2007; Zwaan & Radvansky, 1998). Whenever such discontinuities occur, it is important to have connectives (e.g., because, so that, however), adverbs (finally, previously), transitional phrases (in the next section, later on that evening), or other signaling devices (such as section headers) that convey to the readers that there is a discontinuity.

***Genre and rhetorical structure*.** Genre refers to the category of text, such as whether the text is narration, exposition, persuasion, or description. These major genre categories can be broken down into subcategories within a taxonomy at varying levels of detail. A text has a rhetorical composition that provides a more differentiated functional organization of the discourse. In addition to paragraph organization, there are different rhetorical frames, such as

compare-contrast, cause-effect, claim-evidence, problem-solution and so on (Meyer, Wijekumar, Middlemiss, Higley, Lei, & Meier 2010). Readers will struggle with texts without sufficient training with respect to the structure, pragmatic ground rules, and epistemology of the genres and rhetorical structures of texts (Deane, Sheehan, Sabatini, Futagi, & Kostin, 2006; Eason, Goldberg, Young, Geist, & Cutting, 2012; Meyer et al., 2010; Williams, Stafford, Lauer, Hall, & Pollini, 2009).

***Pragmatic communication*.** Just as a speaker in a conversation has a purpose in conveying a message to the listener (Clark, 1996), the writer tries to convey a message to the reader (Rouet, 2006). A good reader asks why the article was written, what the quality of the source is, and why it useful to read the text. They inquire: What is the point, theme, moral, or message in the text? How is the reader affected by the text?

Aligning technology and the instructional curriculum to theory

The comprehension theory ideally guides instructional curriculum to improve comprehension, whether it be computerized instructional technologies or instruction led by teachers or tutors. When there is blended instruction that includes both computer and human instructors, there ideally is compatibility between the computers and humans.

This alignment between theory, computer lessons, and human instruction was adopted in the CSAL project when AutoTutor was developed for adult learners (Graesser, Cai et al., 2016). The AutoTutor lessons were coordinated with both theory and with a human-led PACES intervention that was modeled after a successful high school reading intervention developed by Lovett and her colleagues in Toronto (Lovett, Lacerenza, De Palma, & Frijters, 2012). That intervention was designed for high school students who were reading between a 3rd and 5th grade level. The teacher-led PACES comprehension lessons consist of didactic instruction, short application activities, and group discussions. Each lesson is devoted to a particular

comprehension strategy that is part of one the five PACES components:

(1) ***P***redicting topic and writer's ***P***urpose with text signals and key information,

(2) ***A***cquiring new vocabulary with context clues,

(3) ***C***larifying common sources of confusion about the text with ***C***larifying questions,

(4) ***E***valuating, ***E***laborating, and ***E***xplaining through questioning,

(5) ***S***ummarizing, identifying, and constructing text ***S***tructures

Strategy instruction is highly scaffolded in the teacher-led delivery of PACES. The teacher leads instruction on one strategy at a time, models and reviews the strategy, provides ongoing support to students applying the strategy, and adjusts and fades prompts over time. As the students acquire greater skill, they take turns being the expert reader guiding the group, following the apprenticeship model that was first introduced by Palincsar and Brown (1984). It is known that effective strategy use requires understanding of the strategies, including when and why to use them (Mason, 2004; Vaughn et al., 2000), so self-monitoring and regulation are important components of the instruction. Students are taught signaling devices used by authors and how these signals can help the students make predictions, identify text structures, and focus on important information.

AutoTutor was closely aligned with the PACES intervention with conversational agents that attempt to provide the oral conversational interaction of teachers or tutors. There are other comprehension instruction curricula developed for K12 and college that have most of the strategy components of PACES (see Crossley & McNamara, 2016; McNamara, 2007), but PACES was the successful human intervention that AutoTutor was designed to emulate. As discussed earlier, it is beyond the scope of this chapter to review comprehension interventions outside of the scope of adult literacy.

The AutoTutor lessons included both the PACES comprehension components (i.e.,

strategies, topics, knowledge components, skills) and additional lessons relevant to forms, electronic documents, and digital technologies. For example, there were lessons on comprehending job applications, rental agreements, digital literacy skills, researching topics on the web to answer questions, email, Facebook, and chat. Reading in the 21st century is not confined to print on paper document but rather encompasses electronic media (Leu et al., 2015; OECD, 2015; Rouet, 2006).

Table 1 shows how the 35 AutoTutor lessons are aligned with the theoretical levels and the PACES curriculum (i.e., P, A, C, E, and S). Each AutoTutor lesson involves one or more theoretical levels: Words (W), syntax (S), textbase (TB), situation model (SM), and genre/rhetorical structure (RS). The pragmatic communication level was not included because that level is highly constrained by the situated context of particular speakers, listeners, authors, audiences, and communication events. Whenever a lesson involved multiple theoretical levels, Table 1 lists them in the order in which the levels were emphasized in the lesson. Thirty of the 35 lessons had 1 or more of the PACES components. Lessons 0, 31, 32, 33, and 34 did not have PACES specification because they addressed digital technologies that were outside of the rubric of the original PACES intervention.

Table 1. *AutoTutor Lessons and Alignment of Theoretical Levels and PACES Curriculum. (W=Word; S=Syntax; TB=Textbase; SM=Situation Model; RS=Genre and Rhetorical Structure)*

AutoTutor Lesson	Theoretical Level	PACES intervention
0. Digital literacy orientation		
1. Text Signals	SM	P
2. Writer's Purpose	RS	P
3. Hybrid Texts	RS,SM	P
4. Prefixes and Suffices	W	A
5. Punctuation	S,SM	A
6. Word Meanings from Context Clues	W	A
7. Acquiring New Words	W	A
8. Multiple Meaning Words	W,S	C
9. Pronouns	TB,W	C
10. Non-Literal Language	SM	C
11. Review	SM,W	P-A-C
12. Key Information to Differentiate Genre	TB,SM	E
13. Questioning Content in Narrative	SM,TB, RS	E
14. Bridge Building in Narrative	SM,TB, RS	E
15. Narrative Structure	SM,RS	S
16. Topic, Main Idea, Support in Informational Text	TB,RS	E,S
17. Evaluating Information in Persuasive Text	TB,RS	E
18. Review	SM,TB, RS	P-A-C-E
19. Statement and Explanation	RS,SM	S
20. Problem and Solution	RS,TB,SM	S
21. Cause and Effect	RS,TB,SM	S
22. Description and Spatial Information	RS,TB,SM	S
23. Compare and Contrast	RS,TB,SM	S
24. Time Order	RS,TB,SM	S
25. Procedures	RS,TB,SM	S
26. Review	RS,TB,SM	P-A-C-E-S
27. Elaborating Inferences in Narrative Text	SM,TB	E
28: Elaborating Inference in Informatival Text	SM,TB	E
29. Elaborating Inferences in Persuasive Text	SM,TB	E
30. Understanding Documents	SM,TB	E
31. On-line Computer Applications	SM,RS,TB	
32. Internet Research	SM,W	
33. Email	SM,TB,RS	
34. Social Media	SM,RS,TB	

The order of lessons for the adult learners to complete is currently a question of debate and there are many options to consider. One alternative is to follow the order of P, A, C, E, and then S, as was done in the original teacher-led PACES intervention (Lovett et al., 2012). A second approach is local-to-global, starting with words, then onto sentences, and finally text structures. A third approach is to follow the ordering of the individual teachers or tutors, in whatever order they want to meet their unique pedagogical vision. This option would have the most flexibility for human-led interventions in classrooms. A fourth approach is for the instructor to select lessons that are sensitive to the idiosyncratic characteristics of the adults(s). This assumes the instructor is capable of diagnosing the particular problems of particular adults; this assumption has not been empirically tested for adult learners. A fifth approach is to have the computer decide what lesson to select next according to computational algorithms that are sensitive to individual adults. A sixth approach is to have the adult learner decide in a self-regulated manner. However, the skills of self-regulated learning are limited for most children and adults, even those with high proficiency (see Azevedo & Aleven, 2013). One direction for future research is to investigate the effectiveness of these different lesson-ordering protocols. Available empirical evidence in the literature does not lead us to prefer one ordering policy over another.

The alignment of educational standards and assessment is also important but it is beyond the scope of this chapter to discuss these mappings in detail. Most of the Common Core standards for reading comprehension (National Governors Association, 2010) are covered by the 35 AutoTutor lessons so we are convinced that our intervention has adequate alignment with pedagogical standards. Regarding assessments, a set of comprehension tests have been identified that cover the theoretical levels of the multilevel theoretical frameworks (Sabatini & Albro,

2012; www.ets.org/research/topics/reading_for_understanding/assessments/).

And finally, there is value in aligning the texts to the theory, curriculum, technology, standards, and assessments. The texts need to have features that have links to the comprehension components under focus. If the focus is on the compare-contrast rhetorical structure, for example, then the text will obviously need to communicate comparisons between some entities. If the strategy involves resolving the referents of pronouns, the text needs to have some pronouns that require comprehension skills to resolve. Computer analyses of text difficulty and discourse levels are two dimensions that are addressed later in this chapter.

AutoTutor: An Intelligent Tutoring System with Conversational Agents

This section describes one digital technology that provides comprehension training in a manner that is tailored to adult learners. The system is *AutoTutor*, an intelligent tutoring system delivered on the web that has conversational agents with synthesized speech and animated facial expressions (Graesser, 2016; Graesser et al., 2016). These conversational agents help individuals learn by performing actions, modeling strategies, and communicating with the adult learner in spoken natural language. The agents are adaptive to the learners' actions in ways described in this section.

AutoTutor has two computer agents (a tutor and a peer) that hold a conversation with the adult and with each other. The three-way conversations are designed to (a) provide instruction on reading comprehension strategies, (b) help the learner apply these strategies to particular texts, (c) assess the learner's performance on applying these strategies, and (d) guide the learner in using the digital facilities. These three-way conversations are called *trialogues* (Graesser, Li, & Forsyth, 2014). Trialogues have also been used in another reading comprehension trainer, *iSTART* (Jackson & McNamara, 2013; Johnson et al., 2017; McNamara, O'Reilly, Rowe,

Boonthum, & Levinstein, 2007), which targets middle school, high school, and college students. The iSTART system has a number of facilities to improve both comprehension and meta-comprehension, i.e., making judgments about one's comprehension processes. The iSTART facility requires the students to type in explanations and elaborations of the meaning of the texts and to bridge explicit text constituents with inferences. One version of iSTART has recently been developed for adult learners in a game environment that is very motivating (Johnson et al., 2017). The writing requirements of iSTART make it suitable for more skilled adult readers who are capable of writing whereas AutoTutor is suitable for adult writers who have challenges typing in contributions more than 3 words. Both AutoTutor and iSTART are designed to adapt to the performance and abilities of adult readers rather than being rigidly scripted, as in the case of the agents in Essential Education lessons.

There is empirical evidence that the AutoTutor conversational dialogues and trialogues with agents have proven successful in improving learning on a variety of subject matters and strategies (Graesser, 2016; Nye, Graesser, & Hu, 2014). Most of the AutoTutor applications have been on topics in Science, Technology, Engineering, and Mathematics (STEM), but AutoTutor included comprehension training in the CSAL project. The AutoTutor trialogues have also been integrated with virtual reality environments in assessments of English Language Learning in addition to STEM subject matters at Educational Testing Service (Zapata-Rivera, Jackson, & Katz, 2015). The testing of AutoTutor to improve comprehension for adult learners is currently under investigation, with some promising early findings on small scale studies (Graesser, Cai et al., 2016). However, the current assessments are being conducted in a blended learning environment that includes teacher instruction, as opposed to AutoTutor alone. The importance of human instructors being in the loop is currently the primary vision in most applications

educational technologies. The amount and type of instructor scaffolding for use of technologies is currently an open question.

As listed in Table 1, the AutoTutor curriculum has 35 lessons that focus on specific comprehension components (Graesser, Cai, et al., 2016). The AutoTutor lessons each take 10 to 50 minutes to complete. Adult learners typically have substantial challenges with writing, so AutoTutor tends to rely on point & click (or touch) interactions, multiple-choice questions, drag & drop functions, and other conventional input channels. However, the system does include some writing components that require semantic evaluation of open-ended student contributions, which is the signature feature of AutoTutor systems (AutoTutor, 2016; Nye et al., 2014) as well as iSTART (McNamara et al., 2007). AutoTutor has many pictures, diagrams, and multimedia that help grab and maintain the attention of the adult learner. The system also has the capability of reading texts aloud when the learner asks for such assistance by clicking on a screen option. This is an important feature because many of the adult learners have limited decoding and word identification skills (Sabatini, Shore, Holtzman, & Scarborough, 2011).

The AutoTutor system took into account the distinctive characteristics of adult learners. For example, it was necessary to design an AutoTutor intervention that makes little or no use of keyboard input (Olney et al., 2017). Instead, there was an emphasis on clicking on visible options on the display, much like an appliance that attempts to make the hidden mechanisms invisible (Norman, 1998). There was the need to create an introductory video on digital literacy to train learners on any particular computer feature that was absolutely essential to include in a particular lesson. For example, scrolling was needed in many of the lessons so that the adults could read lengthier texts. However, only 60% of the adults could do scrolling (Olney et al., 2017). The introductory video included instructions on scrolling in addition to other important

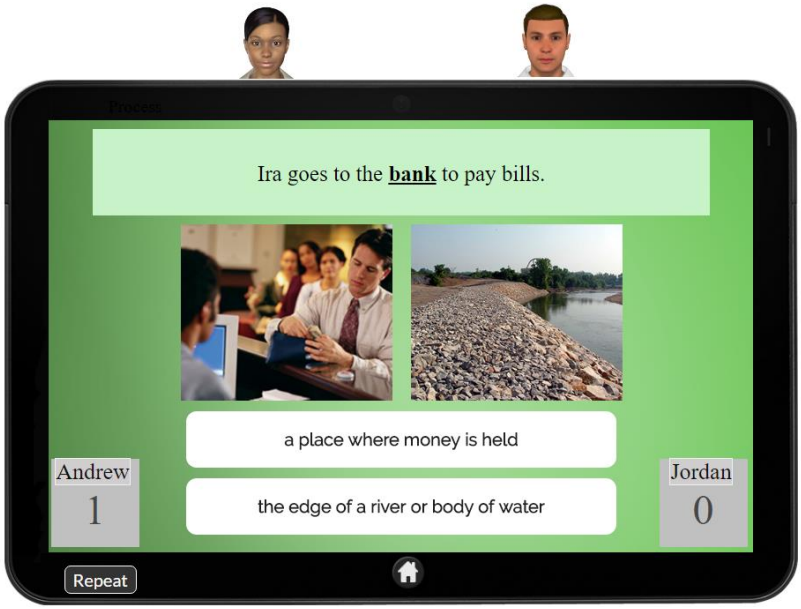
behaviors that many adult learners in the sample had not mastered, as discussed earlier in this chapter. Interestingly, there are many tutorials on digital literacy on the Internet that one might have considered using. Unfortunately, these tutorials routinely assume that the users are able to read at higher levels than the low literacy adults.

Examples of AutoTutor Interactions

Some examples of AutoTutor interactions illustrate how the two agents can scaffold reading comprehension strategies. The first example shown in Figure 1 focuses on the meaning of words in a sentence context. Many words like "bank" have multiple meanings so it is important to use the sentence or passage context to resolve the ambiguity. The example also illustrates a motivational feature, namely a competition between the computer student agent (Jordan) and the adult learner (Andrew). The adult competes with the student agent in a game environment in which points are accumulated. The computer is programmed so that the adult learner always wins or ties the student agent, an approach designed to build self-esteem and a sense of self-efficacy.

Figure 1: *Example Trialogue with competition that focuses on the meaning of words from context.*

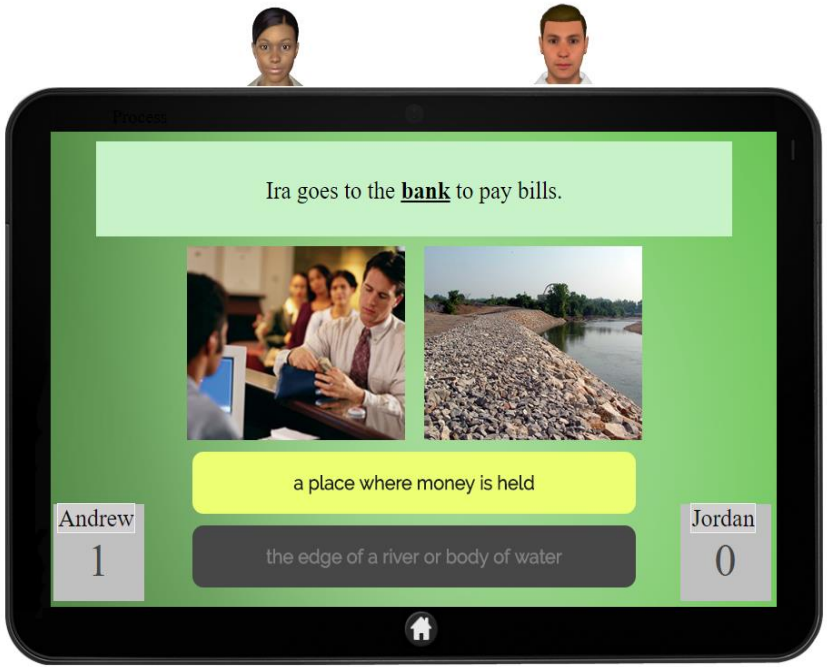
(1) **Cristina (Tutor Agent): What is the meaning of the word bank here? Please click the correct meaning below.**



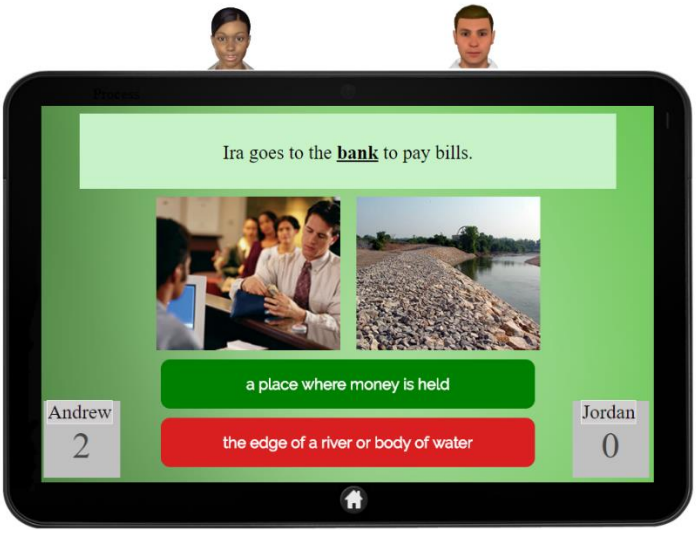
(2) Andrew (Human Student): [clicks on an answer]

(3) Cristina: Jordan, which answer do you think is correct?

(4) Jordan (Computer Student Agent): Maybe the right answer is the edge of a river or body of water.



(5) **Cristina: Andrew, you are correct. Nicely done! Jordan, you are wrong.**
(6) **Cristina: The correct answer for bank is a place where money is held. Ira goes to the place where money is held to pay bills.**
(7) **System:** [Andrew is correct and is given a point, Jordan is wrong and is awarded no points.]



It is important to walk through this example and point out a few details. As a starter, the two agents are perched outside of the main computer interface, much like guides on the side. This design reifies a Vygotskian modelling-scaffolding-fading approach of apprenticeship learning, in which the agents eventually fade leaving the core interface intact. It also is an echo of Bahktin who has emphasized the social conversations that guide our thinking.

Next, the tutor agent is to the left and the student agent to the right. In conversational turn 1, the tutor agent asks both the computer student agent (Jordan) and adult (Andrew) to click on the right meaning of bank. While Andrew clicks after the prompt, Jordan does not. Therefore, Cristina prompts Jordan for an answer in turn 3. This is important to acknowledge. Adult learners need to be prompted frequently when they are lost. This is where the agents can help, just like teachers or tutors do. Essentially the agents are simulating teachers and tutors in a very systematic and sometimes complex manner fashion. Intelligent agents are flexible, arguably more flexible than human tutors (who ideally can adapt to individual learners but they are rarely trained to do so) and teachers (who often focus more on the class, rather than individual learners).

As it turns out, Jordan is incorrect and the student Andrew is correct. This event in conversation-based assessment is a moment when performance can be measured. Just as there are multiple-choice questions in standard psychometric assessment, there is a learner's choice among options on the questions that are asked (see turn 4) or the alternatives on the display (what gets highlighted). However, conversation-based assessment goes a giant step further because the adult learner gets a second chance after feedback and sometimes explanations on the correctness of an answer. Clearly, the psychometric and technology communities are in harmony on some level, but the technology communities are more focused on learning than assessment.

The results of the exchange end up being visible because one entity (student versus agent) wins on points. There is both feedback (turn 5) and explanations by the tutor (turn 6) on what is right or wrong. Finally, the system records the performance (turn 7) and guides the interaction in the future.

There are other features of the human-computer interface that allow the adult learner to have some control over the experience other than clicking on options, scrolling, and occasionally typing in information. There is a "repeat" button to press whenever the learner wants the previous turn of an agent to be repeated. They can press on an option to have text read to them whenever the materials involve a multi-sentence text (but not when a single sentence is presented). They can press the home icon at the bottom whenever they want to start at the beginning. AutoTuor is responsive to these periodic needs of the learner. The system is also responsive to adults who do not initiate a response before a timeout period expires by repeating the agent's question or request. The AutoTutor system was designed to handle any action or non-action of an adult learner at every point in the conversation when the adult is expected to contribute.

Consider next an example in Figure 2 that targets deeper levels of text comprehension in the multilevel framework. As the adults read the text on starting a community garden, they need to consider the appropriate order of events. Figure 2 shows the text and the conversation on how this can be established.

Figure 2. *Example Trialogue on a text that requires ordering events appropriately.*

(1) Cristina (Tutor Agent): Put the steps in order. Jordan, you go first and then Andrew will have a turn.
(2) Jordan (Computer Student Agent): [selects correct answer] **I think the first step is to ask the landowner permission to use the property.**
(3) Cristina: Jordan, you were right. The first step is to ask the landowner for permission to use the property.
(4) **Cristina: Andrew, what comes next? Click on a button.**

This text has the rhetorical structure of a procedure, where a person needs to apply a sequence of actions in a particular order. The order of actions is reflected in the order with which they are mentioned in the passage, but the temporal order may be rearranged by virtue of signal words (i.e., before, after, during, first, and then) that specify the ordering. The tutor directs the student agent and adult to take turns identifying the next step in the procedure by clicking on a sentence, or alternatively on a highlighted word in the passage that refers to a signal word. Sometimes the chronological order is different than the presentation order in the passage. Therefore, reconstructing the mental model of the chronological order is important. That is, the

order of actions requires that the reader be sensitive to both the order of information presented in the text and the signal words. This example is aligned with the *situation (mental) models* level of the multilevel framework that captures, among other things, the chronological order of events and actions as they would unfold in the world; this ordering may deviate from the order of sentences and clauses presented in the text.

There is another characteristic of the trialogue conversation worth noting. The conversation is in what we call the *testing mode* because the tutor is testing the adult or peer agent on their comprehension by asking questions or making a request (turns 1 and 4 in Figure 2), giving short feedback ("you are right" in turn 3), and also providing content that repeats, elaborates, or explains the correct answer (the second sentence in turn 3). When the 35 lessons were designed with AutoTutor, the curriculum developers tried not to rely on this testing mode too often because it has a "schoolish" pragmatic foundation that may turn off many of the adults. The trialogue conversations in Figure 1 has a *game mode*, which is presumably more motivating. Another mode that was frequently used is a *help mode*, where the peer agent needs help with a task and the adult learner is encouraged to help the peer agent. The help mode is designed to increase the adult's self-esteem. These pragmatic conversational modes illustrate how the agent conversation can be designed to enhance motivation in addition to the cognitive comprehension strategies.

Another approach to increase motivation is to use materials that have a practical value for the adult. This is an important contrast with most reading programs that are geared for children. The adult-oriented documents used in AutoTutor either interest many adults or have high practical value, such as getting a driver's license, filling out a job form, changing a flat tire, selecting a smart phone, or treating a burn wound.

There are three components of AutoTutor that provide adaptive interaction. The first assigns texts to read (or shorter instruction episodes) that are tailored to the learner's ability (not too easy or too difficult), as calibrated by prior performance of the learner. A lesson starts out with a text at an intermediate difficulty level, but then increases or decreases the difficulty of the assigned materials in a manner that is sensitive to the learner's previous performance. The difficulty level of the texts is computed by *Coh-Metrix*, a system that scales texts on difficulty by considering characteristics of words, syntax, discourse cohesion, and text category (Graesser et al., 2014; McNamara, Graesser, McCarthy, & Cai, 2014), as described in the next section. After performance is scored on the questions associated with the initial text in a lesson, the next text assigned will be relatively more difficult if the score of is high and will be relatively easier if the adult's score is low.

The second adaptive component designs the trialogue conversations in a manner that adapts to the adults' ability and/or motivation, as reflected in their performance scores during training. For example, there is an AutoTutor activity in which the computer peer competes in a Jeopardy-like game with the adult learner. The learner and peer agent take turns answering questions and score points in the competition that is guided by the tutor agent. Sometimes the learner wins and sometimes the peer agent wins, but ultimately the adult learner manages to end up winning or tying the overall competition, no matter how poorly the adult learner performs. The learner's winning the competition against the peer agent is expected to boost the confidence of the adult learner.

Regarding the third adaptive component, the conversations associated with a particular tutor question depend on the responses of the adult learner. When the adult answers a question correctly when first asked, the adult gets full credit for answering the question. When the adult

answers the question incorrectly, AutoTutor generates a hint and gives the adult a second chance; the adult gets partial credit when the answer is correct on the second attempt. Another approach is to have the peer agent generate information or make a selection and to ask the adult whether Jordan's answer is correct; the adult gets partial credit if they decide correctly. Open-ended responses (that require the learner to type in information using natural language) are assessed with computational linguistics techniques that match the student's input to expectations (Graesser, 2016).

There are auxiliary computer components of AutoTutor that augment the learning experience and motivation. Each AutoTutor lesson includes a short review video of the lesson content in a succinct 2-3 minute segment. There is an online independent reading facility for the adult learners to use. This facility has a text repository (i.e., http://csal.gsu.edu/content/library) with thousands of texts categorized on different topics (such as health, family, work, etc.) and difficulty level. The independent reading facility also provides access to Simple English Wikipedia, a version of Wikipedia for English language learners, and newspaper articles. Adults are encouraged to read documents on topics that interest them, with the guidance and encouragement of the teachers in the adult literacy centers. The hope is that use of the independent reading facility will increase the adults' practice time and self-regulated learning, as discussed in later.

Feasibility Study

A feasibility study was conducted on 100 hours of an intervention on 52 adult learners in Toronto and Atlanta. As mentioned earlier, the intervention was a blended between teacher-led sessions and AutoTutor. The purpose of the study was to gather information regarding the feasibility of running this intervention in authentic adult literacy settings. The results of the

feasibility study were sufficiently encouraging to continue testing on approximately 200 additional adult learners in a study that has been completed and is currently being analyzed.

Self-report data from the adult learners indicated they were very engaged with AutoTutor. They related to the student agent's trials and tribulations, for example, when he had a real world problem that needed reading to help him resolve the situation. The adults sometimes felt sorry for the student agent when he incorrectly answered questions. The students rated the refresher videos as being very helpful succinct and engaging overviews of lessons.

The behavioral performance data were also encouraging. The adults in the feasibility completed 71% of the lessons, which is an excellent retention statistic compared with norms of attrition rates in adult literacy centers (see NRC, 2011). The adults answered 55% of the questions correctly in the AutoTutor conversations, where chance responding is approximately 33%. This level of performance indicates that the questions were sometimes challenging and required hints to scaffold learning. This conversational scaffolding is very different than the traditional computer-based training with multiple choice questions and no scaffolding.

Analysis of Texts on Varying Difficulty and Interest

The assignment of texts to readers is a major concern of teachers and tutors in K12 (Hiebert & Mesmer, 2013; Nelson, Perfetti, D. Liben, & M. Liben, 2011) and surfaces also in adult literacy. Text difficulty is one important criterion to guide such decisions in addition to considerations of interest, curriculum, standards, and suitability of the subject matter for the age group. Sometimes it is important to challenge adult readers by assigning texts on difficulty levels that push the envelope on what they can handle. At other times, they may need a boost in self-confidence by receiving easy texts they can readily comprehend. According to the *Goldilocks principle*, the assigned texts should not too difficult or too easy, but at an

intermediate level of difficulty. Yet another alternative is to have a balanced diet of texts across a distribution of difficulty, with pedagogical assistance available for the difficult texts.

Measures of Text Difficulty

Nelson et al. (2011) conducted a study that compared seven automated measures of text difficulty for scaling texts that range from kindergarten to college-ready. Six of the measures had one unidimensional scale of text difficulty whereas three of them had subscales that correspond to levels on a multilevel theoretical framework (Graesser et al., 2014; Sheehan, Kostin, Napolitano, & Flor, 2014). The measures with subscales are of particular relevance to this chapter because our argument is that it is important to align text characteristics to the other strands of theory, curriculum, standards, assessment, and technology. For example, the text analysis tool that was adopted in the development of AutoTutor was *Coh-Metrix* (Graesser, McNamara, & Kulikowich, 2011; Graesser et al., 2014) because it scaled texts on dozens of components of language and discourse (http://cohmetrix.memphis.edu) that were aligned with the theoretical levels and curriculum shown in Table 1.

The dozens of components of Coh-Metrix funnel into the five major dimensions, each of which are scaled on difficulty and have a correspondence with one of the levels in Table 1. One dimension is *narrativity*, which measures how much a text tells a story as opposed to didactic informational text; this dimension is linked to the theoretical level of rhetorical structure and genre. A second dimension is *deep cohesion*, which is aligned with the situation model, whereas a third dimension is *referential cohesion*, which is aligned with the explicit textbase. The fourth dimension scales texts on the complexity of the *syntax*, whereas the fifth dimension scales texts on *word* abstractness versus concreteness. Coh-Metrix also has an overall metric of *formality* that serves as a single approximate index of text difficulty (Graesser, McNamara, et al., 2014).

Formal discourse is the language of print or pre-planned oratory when there is a need to be precise, coherent, articulate, and convincing to an educated audience. At the opposite end of the continuum is discourse that has a solid foundation in oral conversation, spontaneous language production, and narrative, replete with pronouns, verbs, adverbs, and a reliance on common background knowledge. Graesser, McNamara et al. (2014) reported that texts with high formality increase robustly with grade level and correlate highly (0.66 to 0.72) with other standard metrics of text difficulty, such as Flesch-Kincaid grade level and Lexile scores.

Interest and Independent Reading

The CSAL team developed an independent reading repository (www.http://csal.gsu.edu/content/library) that has thousands of texts classified on difficulty (according to Coh-Metrix and Flesch-Kincaid) and also on topics. Consequently, the adults can choose what to read on the basis of text difficulty and personal interest in the topics. The repository consists of texts on the Web that have low vocabulary difficulty and appear to be interesting according to the research team. Moreover, a survey was administered to 838 adult literacy classroom practitioners to determine what types of texts should be included in the repository. An overwhelming majority of practitioners used both print based resources and resources found online. They reported a considerable use of authentic materials, including newspapers, short stories and biographies, informational materials (such as nutrition, disease preventions) and documents (such as driver's license applications, job applications, bus/train/plane schedules).

Fulmer and Frijters (2011) reported empirical evidence for the intuition that targeting general interests and specific goals of learners is critical to increasing reading motivation. The more frequent the reading engagement, over prolonged durations, the greater the literacy growth

for adults who are struggling with reading (Landauer, Kireyev, & Panaccione, 2011; Reder, 2013; Sheehan-Holt & Smith, 2000). The more one has continued positive and enjoyable experiences with reading, the more there is potential for a reading habit to develop, and the more one reads, the better one becomes in reading (Kim, 2003). That being said, the 100 hours of strategy training in an intervention is a very small dosage compared with the thousands of hours it takes to become a proficient reader. Unfortunately, randomized studies exploring the link between adult interests and reading persistence are rare (see Ainley, Hidi, & Berndorff, 2002), so it is an open question how topic interest is related to time spent reading on the topic.

Closing Comments and Future Directions

Digital technologies are expected to play an increasing role in helping adults learn reading comprehension skills in a world where there are higher expectations on adults in the workforce and the community at large (Carnevale & Smith, 2013; OECD, 2015). This chapter has identified some technologies that provide instruction on comprehension strategies and that expose adults to texts that appeal to their individual interests and abilities. We have proposed throughout the chapter that it is important to align the design of a digital technology to successful pedagogical interventions, curriculum standards, assessments, and text characteristics.

There are major technological and infrastructure challenges that limit the use of technology for improving adult literacy. The obvious elephant in the room is that adults have insufficient scaffolding to using computers and the Internet at home because of the costs of technology and access to instructors. The hope is that these costs will go down and the adults will not be limited to their smart phones in the future. Smart phones indeed support access to the Internet and web site portals, but the screen size is so small that it does not allow visualization of lengthier texts and more

thoughtful reflection on single and multiple documents. In essence, the affordances of smart phones support short interactions and more shallow levels of comprehension.

There is a pressing need to integrate technology in the professional development of teachers and tutors in literacy centers. Professional development is indeed changing with the efforts of government programs and foundations, as discussed earlier. However, most of these efforts are skewed to basic level reading skills or to mere exposure to texts and documents on the Web rather than comprehension strategy training. Relevant training needs to focus more on technologies that improve deeper comprehension skills that adults need to land good jobs, to the use of digital resources, and to a broader landscape of documents than books and magazines.

Technologies to improve adult literacy will not be used without assistance of human teachers or tutors. One important direction for future research is to determine what type of human intervention and how much intervention is needed to guide adults in benefiting from the digital technologies. Some technologies require minimal guidance from instructors whereas others require a higher dosage of instructional scaffolding. Empirical studies are needed to investigate how adult learning and amount of time using a technology varies as a function of type and amount of intervention by human instructors.

Another direction for future research is to investigate characteristics of comprehension instruction that optimize learning. For example, does the ordering of comprehension strategy lessons matter? If so, what orderings are better than others? Which of the comprehension strategies are most effective in improving overall comprehension, as manifested in standardized comprehension tests? How do particular features of comprehension training influence the adults' engagement, emotions, and motivation? The field is nearly at ground zero in answering these basic questions about the role of technologies in improving comprehension in adult learners.

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