Using an Adaptive Intelligent Tutoring System to Promote Learning Affordances for Adults with Low Literacy Skills

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Abstract. One out of six adults in the United States possesses low literacy skills. Many advocates believe that technology can pave the way for these adults to gain the skills that they desire. This article describes an adaptive intelligent tutoring system called AutoTutor that is designed to teach adults comprehension strategies across different levels of discourse processing. AutoTutor was designed with a simple, easy to use interface that caters to the special technological needs of adult learners. Though the interface may be simple, the functionality is not. AutoTutor leverages empirically based learning principles from cognitive psychology to scaffold the acquisition of reading comprehension skills. In particular, it embeds six major learning affordances, or learning opportunities, that help students master difficult material. We provide an overview of AutoTutor, describe its' learning affordances and discuss its potential as a reading comprehension tool. We conclude by considering some of the challenges when building adaptive technologies to support low literacy adults.

Keywords: Adaptive technology · Intelligent Tutoring System · Learning principles

1 Introduction

One in six adults in the United States have literacy skills at a low level of proficiency [1] and face difficulties with daily literacy tasks. Adult education programs offer instruction to help struggling adults (ages 16 and older) improve reading, writing, math, science, and social study skills with the culminating goal of obtaining a high school equivalency degree or a job. Federally funded adult education programs serve an estimate of 2.6 million adults which represents small percentage of the nation's struggling adult readers [2]. Unfortunately, these programs are beset with many obstacles: Poor funding, little professional development for teachers and tutors, high absenteeism and attrition rates, and a diversity of students in terms of racial, ethnic, and gender identities, age (between 16 and 80+), employment, education, language status, and psychosocial attributes of esteem, anxiety, and motivation. As a result of these obstacles, administering quality adult literacy instruction has been a challenge [3] and attempts to improve the literacy of these adults have been disappointing.

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The difficulties of adult literacy instruction have led some to advocate the use of adaptive learning technologies on the Internet as a possible solution [4]. Being able to access a computer program on the Internet is an excellent way to combat absenteeism due to unstable work hours, transportation difficulties, and childcare issues. Computers with Internet access are available for adult learners in public libraries, children's schools, and adult literacy programs. Newnan's [5] 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 [6] reported that an increasing number of adult literacy programs are infusing technology into their classrooms and curricula. On other hand, a major challenge lies in developing technology that addresses the poor digital literacy skills of adults in the United States [6]. Olney, Bakhtiari, Greenberg, and Graesser [7] recently tested the digital literacy ability of 114 adults reading below the 8th grade level. Even though 72% of the adult learners reported using a computer for five or more years, 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. Thus, technology geared for adult learners needs to be understood easily by adult learners, include scaffolding to help them use the technology, and minimally depend on open-ended learner input such as writing (because poor readers are able to write very little).

One solution to handling the limited digital literacies of adult readers is to use conversational agents as part of the technology [4]. Conversational agents are talking heads or avatars that speak to the adult with pre-recorded 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. An Intelligent Tutoring System (ITS) called AutoTutor was designed with conversational agents in order to teach comprehension skills to adults who read between a 3rd and 8th grade level.

Besides providing a simple, intuitive design and abundant scaffolding, AutoTutor has a number of characteristics of educational environments that facilitate learning. Old-school media consisted of listening to lectures, watching video presentations, and reading books. For these media, the learners passively observe or linearly consume the materials at their own pace. However, the learning environments in today's world require learners to be more active by strategically searching through hypermedia, constructing knowledge representations from multiple sources, performing tasks that create things, and interacting with technologies or other people [8, 9]. From the standpoint of technology, it is worthwhile for technologies to embody characteristics that facilitate active, constructive, interactive learning environments. The National Academy of Sciences, Engineering, and Medicine [10] identified 8 characteristics, referred to as affordances, of advanced learning technologies that are grounded in cognitive and educational psychology principles/strategies. The affordances that AutoTutor implements for adults with lower reading literacy include interactivity, adaptivity, feedback on performance, choice, linked representations, and communication with other people or agents. AutoTutor includes the 2 other affordances (nonlinear access and open-ended learner input) but only minimally.

The AutoTutor technology has been used to develop modules for 35 comprehension strategies that cover different levels of reading comprehension, including words, the explicit text, the referential situation model, rhetorical structure, and discourse genre [11]. A 4-month hybrid intervention that included human tutors in addition to AutoTutor was conducted on 252 struggling adult readers in Toronto and Atlanta. Fang et al. [12] reported improvements on three psychometric measures of comprehension in a pretest-posttest design, with effects sizes that varied from .12 to .63 for four clusters of readers.

This paper describes AutoTutor for struggling adult readers and reports highlights of empirical findings that speak to its efficacy. A primary emphasis is on the affordances of AutoTutor's interface and pedagogical strategies that are grounded in learning principles and as such should improve adaptive computer-based tutoring for struggling adult readers. We first give an overview of the AutoTutor system, and describe some general considerations in building educational technology for low literacy adults. We then describe what is meant by "learning affordances" of technology and describe six primary affordances of AutoTutor that support active deeper knowledge acquisition and learning. Finally, we turn to studies that consider the effectiveness of AutoTutor as a reading comprehension tool for the struggling adult reader. We conclude with some recommendations for future research in the area of adaptive learning environments for adult literacy students.

2 Overview of AutoTutor for Reading Comprehension

AutoTutor is a conversational ITS that teaches adults reading comprehension skills by holding conversations in natural language. These conversations are called "trialogues" because two computer agents, a teacher (Christina) and a peer student (Jordan), engage one adult learner in discussion about course topics. The "talking heads" help adults learn by interacting with them through speech and by frequently referring to texts and multimedia. They scaffold students through different types of reading comprehension strategies (e.g., clarifying pronouns, identifying main ideas, understanding compare-contract structures) and also help with navigating the computer environment.

The AutoTutor curriculum has 35 lessons that focus on specific comprehension components [13]. Each AutoTutor lesson takes 10 to 50 min 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 and drop functions, and other conventional input channels. However, the system does include some writing components that require semantic evaluation of open-ended student contributions. 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 [14].

When the AutoTutor system was being created, the designers took into account the distinctive characteristics of adult learners. For example, it was necessary to have an AutoTutor intervention that makes little or no use of keyboard input [7]. 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 [15]. 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 [7]. 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 adults with low literacy. In the next section, we see how, despite the limitations of low literacy adults when it comes to technology, AutoTutor successfully implements many possibilities to support learning in the area of reading comprehension.

3 Learning Affordances

Learning technologies like ITSs open up significant opportunities to support learners. The term "affordance" refers to opportunities a technology makes possible related to learning and instruction [10, 16]. For example, a bench affords users a way to sit, whereas a staircase affords users the ability to reach higher ground. Certain features of contemporary digital environments including multimedia displays with texts, pictures, diagrams, visual highlighting, sound, spoken messages, and input channels (clicking, touching) for entering information can afford important learning opportunities for users. The learning environments in today's world require learners to be more active by strategically searching through hypermedia, constructing knowledge representations from multiple sources, performing tasks that create things, and interacting with technologies or other people [8, 9]. From the standpoint of technology, it is worthwhile to take stock of the characteristics of learning environments that facilitate active, constructive, interactive learning environments. Table 1 shows some of these characteristics that were identified by the National Academy of Sciences, Engineering, and Medicine in the second volume of How People Learn [10]. It is important to consider these characteristics when creating technologies to support the acquisition of knowledge.

Table 1. Key affordances of learning technologies (NASEM, 2018).

Affordance	Description
1. Interactivity	The technology systematically responds to the actions of the learner
2. Adaptivity	The technology presents information that is contingent on the behavior, knowledge, or characteristics of the learner
3. Feedback	The technology gives the learner information about the quality of their performance and how it could improve
4. Choice	The technology gives learners options on what to learn and how to regulate their own learning

(*continued*)

Table 1. (*continued*)

Affordance	Description
5. Nonlinear access	The technology allows the learner to select or receive learning activities in an order that deviates from a set order
6. Linked representations	The technology provides quick connections between representations for a topic that emphasizes different conceptual viewpoints, media, and pedagogical strategies
7. Open-ended learner input	The technology allows learners to express themselves through natural language, drawing pictures, and other forms of open-ended communication
8. Communication	The learner communicates with one or more people or agents

4 Learning Affordances of AutoTutor

In this section, we discuss how AutoTutor embeds six primary learning affordances empirically shown to support learning. They are *Interactivity, Adaptivity, Feedback, Choice, Linked Representations, and Communication* with other people. For each affordance, we describe the cognitive or educational principle that it reflects. We then demonstrate how this affordance is captured in AutoTutor.

4.1 Interactivity

Unlike static textbooks, audiotapes or films, an interactive system presents new information in response to the learner. Underlying interactivity is the idea of a two-way action (between learner and instructor) as opposed to a one-way action (i.e., from instructor to learner) that helps the learner change his or her knowledge to promote learning [17]. AutoTutor was designed as an interactive system that responds to the actions and even non-actions of adult learners in an effort to promote understanding. For example, interactivity occurs at the level of question asking and answering. After the user selects an answer, the system responds with a sound that tells the user he or she was either correct (higher pitched chime) or incorrect (lower pitched beep). In the case of an incorrect response, the student is often asked to interact further with the system and provide a different answer. In addition, there are responses to more unique actions of the users. For instance, there is a "repeat" button to press whenever the learner wants the previous turn of an agent to be repeated. Users 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, and the system will return them to the start. AutoTutor 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 handles any action or non-action of a learner at every point in the conversation when the learner is expected to contribute. This system behavior increases interactivity and guides the user toward specific learning goals.

4.2 Adaptivity

There is good evidence that instruction is more effective if it takes into account that learners are different and that they change as they learn [18]. For example, task selection based on assessment of individual students' knowledge can contribute to the effectiveness of instruction [19, 20]. AutoTutor was designed to be adaptive to help foster learning. In particular, 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 [21, 22]. 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 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 [23]. In this way, AutoTutor scaffolds learning by being adaptive to the ability or motivation of the learner as well as his or her progress throughout the lesson.

4.3 Feedback

There is a wealth of evidence that feedback powerfully influences learning outcomes. From a review of 12 meta-analyses that included information regarding feedback in classrooms, the average effect size was $d = .79$, which is twice the average effect of other academic influences [24]. Feedback can make learning visible to the student, can

lead to error detection, and enhance students' assessment capabilities about their learning [25]. Feedback is central to the AutoTutor system. For each response the user gives, AutoTutor provides the learner information about the quality of their performance and how it could improve. The feedback is both timely and takes into consideration the abilities of the adult learner.

There are three main ways the AutoTutor system provides feedback. First, when a user submits an answer, they hear a sound (either a negative "wonk" or a positive "chime") that quickly alerts them to whether they answered correctly or not. Second, following the correct or incorrect sound, the user hears what is called a "canned response". This is a general response such as "nice job" or "that's not quite the answer we want", depending on the correctness of the given answer. The canned response for incorrect answers tries to be more neutral in feedback, since adult learners may struggle with confidence. These responses are typically, "Sorry, i was thinking of a different response" or "Hmmm, that is not the best answer in this case" which lets the user know his or her answer was not correct, but without being inadvertently disparaging. The canned response for correct answers is very positive, using phrases like "Yes! That's it! Way to go" or "Nice work. You are really getting the hang of this". When canned feedback comes from the peer agent, it is often in the sense of the student peer benefitting from the wisdom of the adult learner. Phrases such as "Wow, I had no clue that was the answer. Thanks so much for your help!" or "[Adult learner's name], thanks for choosing the right answer. You are helping me so much" may boost the learner's confidence and motivation.

The third type of feedback comes after the canned feedback, when the system provides more specific feedback to the user regarding the question. The correct answer on the screen is highlighted in green, and an agent describes why this answer is correct in one or two clear sentences. If the tutor agent provides the explanation, it may be followed up with the peer agent summarizing this information with a statement such as "Oh i get it now. So certain words like 'first' or 'then' can help us determine the order of steps in a procedure." In this way, feedback can come from both agents in order to help pinpoint the correct answer and add clarification. In general, AutoTutor attempts to provide timely, clear and relevant feedback to enhance learning.

4.4 Choice

Research supports the idea that instruction that gives students a choice in what to learn and when to learn it is generally considered better than instruction in which all students follow the same scope and sequence at the same pace [26]. As such, AutoTutor gives learners options on what to learn and how to regulate their own learning. Though AutoTutor was initially designed to act as a web-based component of an instructor led course that followed a particular curriculum, the program can act as a stand-alone reading comprehension tool. The program is web-based, and anyone at any time can access any of the available lessons. This affords adult learners the choice of developing their skills at their pace in a variety of environments, including their home. AutoTutor lessons are divided into three main categories: Words, Texts and Stories, and Computer and Internet. Each lesson was meant to stand alone, independent of other lessons so that adults can work on any lesson within any category. If they find certain lessons too

difficult, they can choose a different lesson more suitable to their level, for example, choosing a lesson from Words instead of Texts and Stories. Within the lessons themselves, learners have choice. For example, there are three "Jeopardy!" style lessons where the human student and the peer agent answer questions in a jeopardy style fashion. At each turn, the user chooses what question to receive from among a board that contains 16 questions corresponding to different topics and having different point values.

Early versions of AutoTutor also included auxiliary computer components that augment learning experience and motivation, and similar features are being considered for the present version. For example, 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.

4.5 Linked Representations

The use and construction of different representations to inform on the same concept can promote a deeper understanding of domain concepts that would be difficult to achieve with a single representation [27]. The ability switch between multiple perspectives in a domain helps learners build abstractions necessary for a grasp of domain content [28]. Furthermore, insights achieved through the use of multiple representations increases the likelihood that knowledge acquired will transfer to new situations [29]. AutoTutor was designed to provide quick connections between representations for a topic that emphasizes different conceptual viewpoints, media, and pedagogical strategies. As such, it helps promote deeper learning and cognitive flexibility.

For example, the majority of lessons include a 2 min video tutorial called a "nutshell" that gives the learner a brief visual and audio overview of the lesson topic. This tutorial is typically viewed before a user begins a lesson, but may be accessed at any point during the lesson by pressing on a "watch video" button on the bottom of the screen. AutoTutor also uses visuals such as charts or diagrams to enhance learning. For example, Fig. 1 shows a diagram used at the beginning of the lesson "Connecting Ideas" that helps the user build a model of how the characters and events of stories interrelate. These visuals may be presented during the opening dialogue, when the student agent and tutor agent are giving an overview of the lesson. Like the nutshells, the user can often access these visuals throughout the lesson with a click of a button. Often, these visuals appear again at the end of the lesson, while the agents are recapping what was learned. The goal is to facilitate learning by modeling information in multiple ways to help the user build a coherent representation of the topic.

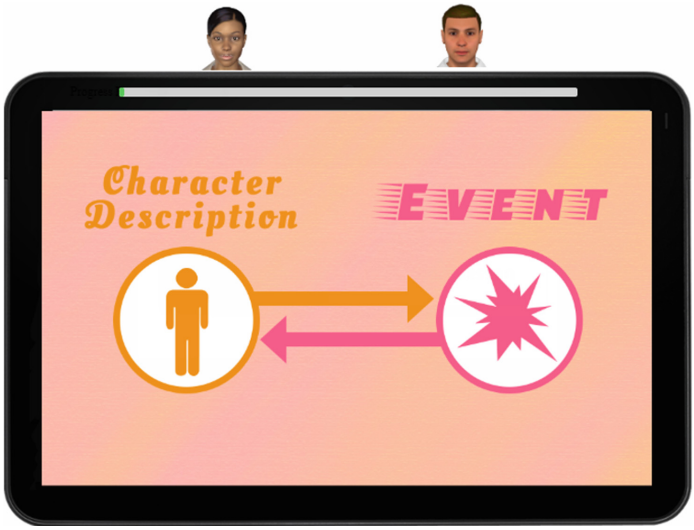

Fig. 1. An example of AutoTutor's use of linked representations. This diagram depicts relationships between characters and events, a key concept within the lesson "Connecting Ideas". The concept this diagram reflects is represented throughout the lesson in other ways including text, pictures and conversation.

4.6 Communication

For the learner, conversations provide multiple opportunities and resources for the development of intellectual competencies and positive motivational orientations toward learning [30]. As described previously, conversation is at the heart of AutoTutor, and is used to scaffold learning in students. When using AutoTutor, the learner communicates with a peer agent and a tutor agent in what is called a trialogue. The presence of both a tutor agent and a peer agent make possible three primary conversation modes in AutoTutor- *testing mode*, *game mode* or *help mode*. In testing mode, the tutor tests both the adult and peer agent on their comprehension by asking questions or making a request, giving short feedback ("you are right"), and also providing content that repeats, elaborates, or explains the correct answer. When lessons were being designed for AutoTutor, 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 also have a game mode, which is presumably more motivating. Another mode that is 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 and feelings of positivity toward learning. These types of communication illustrate how the agent conversation can be designed to enhance motivation in addition to improving cognitive comprehension strategies.

5 Effectiveness of AutoTutor as a Reading Comprehension Tool

The primary goal of AutoTutor is to increase reading comprehension skills in lower literacy adults. The six affordances within AutoTutor reflect cognitive principles known to enhance learning, and as such, should facilitate the acquisition of reading skills in adult learners. We have recently begun to explore the question of how effective AutoTutor is for reading comprehension. At this point, we have considered the effectiveness of AutoTutor by analyzing data from 52 adult literacy students who interacted with AutoTutor in a 100 h intervention designed to improve their reading skills [4]. The intervention was a blended between teacher-led sessions and the computer based AutoTutor. The purpose of the study was to gather information regarding the feasibility of running this intervention in authentic adult literacy settings.

Self-report data from the adult learners indicated that 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, "nutshell" videos as being very helpful, succinct, and engaging overviews of lessons.

The behavioral performance data were also encouraging. The adults in the feasibility study completed 71% of the lessons, which is an excellent retention statistic compared with norms of attrition rates in adult literacy centers [2]. 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 the system to adaptively offer hints to scaffold learning. This conversational scaffolding is very different than traditional computer-based trainings that do not adapt to the user's response and provide only multiple choice questions with no scaffolding. 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. This additional data will help us determine whether AutoTutor is a viable approach to possibly improve adult readers on comprehension strategies and skills.

6 Discussion

Digital technologies are expected to play an increasing role in helping adults learn reading comprehension skills in a society where there are higher expectations on adults in the workforce and the community at large [31, 32]. As such, it is critical that learning technologies take heed of empirical evidence regarding what works and what does not work in order to effectively promote knowledge acquisition. This paper described an adaptive ITS called AutoTutor that was designed with learning affordances that reflect empirically based cognitive principles of learning. We provided examples of how AutoTutor implements six of eight affordances that help facilitate aspects of successful learning environments.

While early results suggest that AutoTutor is a promising technological tool for low literacy adults, more data needs to be collected and analyzed, and there are further challenges to address. For example, adults with low literacy skills tend to vary not only in demographic variables (age, gender, and race/ethnicity), but also with respect to educational backgrounds, learning disabilities, primary languages (English or other) and motivation to improve their literacy level [2]. Furthermore, Fang et al. [12] showed that adult readers have distinctive behavioral profiles when it comes to learning. There are higher performing readers who may benefit from more challenge and should be encouraged to increase their reading activities. There are conscientious readers who benefit by spending extra time on the material and questions, unlike struggling readers who also spend a good amount of time on the material but show minimal gains. There are also underengaged readers who would benefit from reminders to concentrate or more motivating material. By leveraging the multiple affordances of AutoTutor such as adaptivity, linked representation and choice, it is possible to better deal with this variation in both background and behavior. A future hope is that we can improve learning by tailoring instruction and materials to meet the various needs of the individuals in this group.

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