EMBRACE: Applying Cognitive Tutor Principles to Reading Comprehension

Erin Walker[1], Audrey Wong[1], Sarah Fialko[2], M. Adelaida Restrepo[3], Arthur M. Glenberg[2]

[1]Computing, Informatics, and Decision Systems Engineering, Arizona State University, USA
[2]Department of Psychology
[3]Department of Speech and Hearing Science
erin.a.walker, aewong, sfialko, marestre, aglenber@asu.edu

Abstract. Reading comprehension is a critical skill, and one where dual language learners can fall behind compared to native English speakers. We developed EMBRACE, an intelligent tutoring system to improve reading comprehension of dual language learners. Based on theories of embodied cognition, EMBRACE tutors children on how to create cognitive simulations of text content. We describe the implementation of EMBRACE and show how it is closely aligned to principles posed by Anderson and colleagues in 1995 for the design of cognitive tutors, a type of intelligent tutoring system.

Keywords: embodied cognition, cognitive tutors, reading comprehension

1 Introduction and Related Work

Many children who learn English as a second language (dual language learners, or DLLs) tend to perform poorly in English reading comprehension compared to their monolingual counterparts [1]. Our research explores the way in which intelligent tutoring systems (ITSs) can help DLLs develop their reading comprehension skills. ITSs understand the ways in which students solve problems and provide tailored help and feedback [2]. Developing an ITS for reading comprehension has several challenges. Unlike problems in math or science, in which students typically employ a small set of skills to follow a clear path to a correct answer, problems in reading relate to several complex interconnected skills that are highly context dependent [3]. Nevertheless, there have been several ITSs developed for language learning, including REAP [4], iSTART-2 [5], ITSS [6], and Project LISTEN's Reading Tutor [7].

In this paper, we describe *EMBRACE*, an ITS for DLL reading comprehension. Like iSTART-2 and ITSS, *EMBRACE* instructs children on reading comprehension strategies, and provides them with immediate feedback on their strategies. Like REAP and The Reading Tutor, *EMBRACE* tracks student comprehension skills, and uses this information to give vocabulary or syntax feedback and select subsequent learning activities. *EMBRACE*'s approach is unique in how it uses the reading comprehension strategy of cognitive simulation to model ideal performance and provide support.

2 *EMBRACE* Implementation

EMBRACE draws from an embodied cognition approach that posits that language comprehension is a cognitive simulation process [8]. The primary goal of *EMBRACE* is to teach children how to engage in this simulation process. The application is an interactive storybook on the iPad with a library of narrative and expository texts, of five to seven chapters. In each chapter, each page has images depicting a scene and sentences are displayed in a text box. Students tap on a "Next" button to advance from sentence to sentence. The current sentence is displayed in either blue (manipulation sentence) or black (non-manipulation sentence). For manipulation sentences, children read the sentence and then perform the action using the story images. Children touch an image to select it and drag it to the desired position, moving one object to another object or location. When the user makes an error, a noise is played, and moved objects are reset.

Figure 1. EMBRACE. Students move images corresponding to the highlighted sentence.

EMBRACE provides children with direct feedback on their simulations. Suppose the child is trying to comprehend the highlighted sentence in Figure 1, "*Sofia grabbed the bowl of red chilis and gave it to her mother to grind them.*" If the child moves Sofia to the bowl, then Sofia and the bowl together to the mother, these actions provide evidence that the child can identify Sofia, and understands the vocabulary words "bowl" and "mother." However, if the child moves Sofia to the money on the table, this would indicate that the child successfully identified Sofia, but not the words "bowl" or "money". In contrast, if the child moves the bowl to Sofia, this may mean that the child understands both vocabulary words, but misunderstands the syntax of the sentence. To determine whether the child has made a vocabulary or a syntax error, the application divides each sentence into manipulation steps, and each manipulation step into the object to be moved (the source), and the destination object or location (the destination). It tracks the current manipulation step, and assesses the child's actions based on whether the source (vocabulary error), the destination (vocabulary error), or the sequence of actions (syntax error) is incorrect. Using this information, *EMBRACE* updates assessments of the child's vocabulary and syntax skills. Vocabulary skills are further divided into specific words (e.g., bowl, money), whereas syntax skills are divided into simple, medium, and complex, mapping to the syntactic complexity of the current sentence. Values of skills range from 0 to 1, and represent an estimate of the probability that students have mastered a particular skill. Extending our example, if the child moves Sofia to the money, the skill associated with Sofia would increase, while the skills associated with bowl and money would decrease. These adjustments are made using a Bayesian knowledge tracing algorithm [9], and it is possible for multiple skills to be adjusted as a result of a single action.

Based on the updating skills, *EMBRACE* gives the child vocabulary and syntax feedback if a skill related to that error decreases, and falls below a feedback threshold (set to 0.50). Thus, students only receive feedback if there is a reasonable probability that they have not yet mastered the skill. *EMBRACE* provides vocabulary feedback by playing a feedback noise and temporarily highlighting the correct objects involved in the step. The system provides syntax feedback by playing a feedback noise and reading the sentence out loud to the child.

EMBRACE additionally adapts the learning activity in two ways based on the child's skills. First, each chapter begins with a list of target vocabulary words that are introduced in the text (called the vocabulary preview). The user taps on each word to hear its pronunciation and definition and to see the corresponding image. Vocabulary previews are adapted by adjusting the list of words that appear in the beginning of each chapter. The list always starts with new words and definitions introduced in the chapter and difficult words from the previous chapter. Additional words are added to the list if they: a) appeared in a previous chapter, b) appear in the following chapter, and c) have a skill value below a threshold of 0.80. At most, eight words appear in this list to not overwhelm the child. Second, syntax is adapted by adjusting the complexity of sentences at the beginning of a chapter. For example, if a medium complexity version of a sentence was, "He carried the full milk bucket to the cat," the complex version might be, "Then, he carried the milk bucket, that was full of milk, to the cat." By default, the user starts at medium complexity for the first chapter of a story. Afterwards, if her simple syntax skill is below 0.90 or her medium syntax skill is below 0.40, then the following chapter will switch to mostly simple sentences. If her medium syntax skill is below 0.90 or her complex syntax skill is below 0.40, then the chapter will switch to mostly medium sentences. Otherwise, the chapter will switch to mostly complex sentences. All thresholds were assigned through piloting and testing the application, to trigger feedback at reasonable times.

3 Discussion and Conclusions

In this paper, we described *EMBRACE,* an ITS for DLL reading comprehension of primary school children. Historically, building ITSs has been challenging to for reading comprehension, because of the complexity and contextual embeddedness of the skills involved. However, *EMBRACE* is a traditional implementation of an ITS, and fulfills Anderson and colleagues' [2] eight basic principles of tutor design. In

EMBRACE, we decomposed the task into production rules related to the manipulation actions (Principle 1), made the manipulation goals evident to the students (Principle 2), and ground instruction in the specific context of the stories (Principle 3). From a theoretical perspective, embodied cognition is highly congruent with traditional cognitive tutoring approaches in that it allows for fine-grained modeling and immediate feedback. Further, *EMBRACE* provides immediate feedback on vocabulary and syntax skills (Principle 6), adjusts the amount of feedback based on student skills (Principle 8), adapts the complexity of the texts based on student skills (Principle 5), and presents students with additional vocabulary mapped to vocabulary skills they have not yet mastered (Principle 7). *EMBRACE* is novel in the way it coaches children on the reading comprehension strategy of simulation, but also helps them acquire the content-specific vocabulary and syntax skills that form the foundation for reading comprehension. By centering our ITS on the concept of simulation (reified through manipulation actions), it was possible to fulfill many of Anderson and colleagues' [2] cognitive tutor principles. We see a lot of promise in this approach for improving the reading comprehension skills of young DLLs using personalized learning.

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