When (and how) interacting with technology-enhanced storybooks helps dual language learners

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Abstract

In a meta-analysis, Takacs, Swart, and Bus (2015) found that when children listen to multimedia electronic storybooks, comprehension is higher than when listening to a traditional oral reading of the story. However, adding interactive features reduced the benefit, and for at-risk children, the interactive features reduced comprehension to below that when listening to the reading. Here we report a contrasting effect. Namely, a type of interactive feature that we call simulation has a large positive benefit on story comprehension in a multimedia environment for dual language learners. In addition, we show that combining simulation with a modicum of support in the native language (in this case, Spanish) produces additional benefits on reading comprehension. That is, when children are poor decoders but have good English language skills, or when they are good decoders but have poor English language skills, adding Spanish support to simulation makes up for the deficit and increases performance when reading in English. We trace the differences between our findings and those reported by Takacs et al. to the types of interaction used. In the Takacs et al. findings, the interactive features did not enhance story meaning. In the current research, simulation was specifically designed to highlight meaning. Thus, simulation and Spanish support may be effective for improving comprehension when dual language learners are reading in English.

Keywords: reading comprehension; dual language learners; embodied cognition; interaction; EMBRACE

Public significance: Young dual language learners often fare poorly on tests of reading comprehension. We tested an iPad application, EMBRACE, based on principles of embodied cognition and designed for young, Latino dual language learners. The application significantly enhanced comprehension of both narrative and expository texts.

Reading comprehension is a critical skill for academic success. However, it is a problem for many children, including language-minority children and second language learners. In Arizona, the 2015 NAEP found that only 44% of white fourth graders were classified as proficient or better readers, and only 18% of Latino fourth graders were classified as proficient or better (National Center for Education Statistics, 2015). The increased use of technology in literacy instruction may work towards closing this gap (Jiménez, 2003; Proctor, Dalton, & Grisham, 2007; Strangman & Dalton, 2005).

We report on a technological intervention we call EMBRACE (Enhanced Moved by Reading to Accelerate Comprehension in English) that is designed to enhance comprehension of written English by Latino dual language learners (DLLs). EMBRACE contains interactive features that facilitate the **simulation** of story events. As a child reads the text on an iPad, he or she uses touch-based interaction to manipulate images on the screen, demonstrating the meaning of the sentences he or she reads. For example, if the sentence is, “The cat drank the milk to make her fur shiny,” the child moves an image of the cat to the milk bucket. In addition, EMBRACE has a collection of features called **Spanish support,** which provides help to students in their native language in addition to in English. Our data show large benefits of simulation, and for some children, additional benefits when simulation is combined with Spanish support.

In this paper, we review the use of interactive learning environments for reading comprehension and the benefits of Spanish support. We describe EMBRACE and present a study where we compared EMBRACE against interventions without simulation and without Spanish support. We analyze the effects of our intervention, the influence of prior language ability, and the mediating role of help-seeking within the system.

Background

Interactive Features & Simulation

Simulation, one of the key components of EMBRACE, is based on theories of embodied cognition that posit that language comprehension is a cognitive simulation process (Barsalou, 1999; Glenberg & Gallese, 2012). Words and phrases drive sensorimotor and emotional cortices into states homologous to those generated by literally being in the situation described by the language. Thus, on reading or listening to a sentence such as, “The couple held hands while walking down the moonlit beach,” the emotional system is activated (Havas, Glenberg, Gutowski, Lucarelli, & Davdison, 2010) to simulate and induce emotion; the motor system is activated corresponding to walking (Hauk, Johnsrude, & Pulvermüller, 2004); and the visual system is activated to represent the visual components of a moonlit beach (Kaschak et al., 2005). There is empirical evidence to support the benefits of simulation. It has been shown to improve children's comprehension abilities during reading and listening in a variety of contexts (Glenberg, 2011). Both English monolingual (Glenberg, Gutierrez, Levin, Japuntich, & Kaschak, 2004) and Spanish monolingual (Adams, Glenberg, & Restrepo, 2015) children benefit from simulation when reading simple narratives. Also, simulation can help children to more accurately solve mathematical story problems (Glenberg, Willford, Gibson, Goldberg, & Zhu, 2011). Nonetheless, not much is known about how the use of interactive technologies might further benefit simulation practice.

In addition, previous research has yet to determine whether simulation will be equally beneficial when children read expository texts, rather than narrative ones. Studies have shown that it is difficult to generalize reading comprehension of narratives to reading comprehension of content area text primarily because of the level of decontextualized academic language used in the latter (Snow, 1991). The relative difficulty of the text and the content interact with the skills and previous knowledge of the reader to determine how much of the text will be comprehended. Because the language structures used in expository texts are not often used in everyday language, simulation may need to be taught explicitly.

In this project, we investigate two research questions related to simulation processes in DLLs. First, **RQ1a**: *Does simulation practice improve DLL reading comprehension of narrative texts over traditional reading practice?* Second, **RQ1b**: *Does simulation practice improve DLL reading comprehension of expository texts over traditional reading practice?* For both research questions, we hypothesize that simulation will indeed improve reading comprehension over traditional practice.

Spanish Support

Our second set of research questions relate to the Spanish support component of EMBRACE. Use of a child's native language in literacy instruction and oral language interventions can be helpful in improving reading and listening comprehension in a second language. This is especially true for children who learn to read in their first language. Several meta-analyses, including the report from the National Literacy Panel concerning DLLs (August & Shanahan, 2006), have reported that children who learn to read in their native language demonstrate higher levels of achievement in English literacy skills (Genesee, Lindholm-Leary, Saunders, & Christian, 2006; Greene, 1997; Rolstad, Mahoney, & Glass, 2005; Slavin & Cheung, 2005). These results are likely due to the phenomenon of cross-linguistic transfer, where people apply knowledge from one language to another. However, the results are not as clear for children in subtractive bilingual environments in which English-only education is the norm and differences in the social standing of the two languages are pronounced, as is the case of Spanish in several states in the United States. In these cases, English oral language and early literacy skills often mediate the relationship between Spanish abilities and English reading comprehension outcomes (Gottardo & Mueller, 2009; Mancilla-Martinez & Lesaux, 2010; Manis, Lindsey, & Bailey, 2004).

Two types of strategies may influence cross-linguistic transfer from the first to the second language. First, children's use of cognate strategies to determine the meanings of novel words in English is an important predictor of comprehension, but orthographic transparency of the cognate words mediates this relationship (Dressler, Carlo, Snow, August, & White, 2011). More successful DLL readers are more likely to implement successful cognate strategies (Jiménez, García, & Pearson, 1996), and cognate strategies are an important area of cross-linguistic transfer for L2 readers (Durgunoglu, Nagy, Hancin-Bhatt, 1993). This factor may be particularly relevant for expository texts that contain scientific words, which are often cognates (Beck, McKeown, & Kucan, 2002). Second, higher-level cognitive comprehension strategies might also facilitate cross-linguistic transfer. Inferencing, comprehension monitoring, and repair have been found to be crucial to successful reading comprehension, both among monolinguals and bilinguals (Cain 1996; Dickinson, Golinkoff, & Hirsh-Pasek, 2010; Kendeou, van den Broek, White, & Lynch, 2009). Klingner, Artiles and Barletta (2006) found that DLL children who were poor comprehenders tended to focus more on surface aspects of the text and were less efficient at using comprehension strategies while reading. Langer, Bartolome, Vásquez, and Lucas (1990) found that children who were good comprehenders made more inferences and used repair strategies more successfully while reading. Poor comprehenders were more likely to continue reading without attempting to repair breakdowns in comprehension.

Thus, we pose two further research questions. First, **RQ2a.** *Does Spanish support enhance the effects of simulation activities to improve reading comprehension of DLLs for narrative texts?* Second, **RQ2b.** *Does Spanish support enhance the effects of simulation activities to improve reading comprehension of DLLs for expository texts?* We hypothesize that the Spanish support will indeed improve the reading comprehension of students engaging in simulation for both types of texts.

Method

To test these questions, we randomly assigned 93 Latino DLL students to read both a narrative and expository text in one of four conditions, corresponding to a 2 x 2 between-subject factorial design. One factor was language: children either received support in Spanish and English (which we are calling Spanish support), or in English alone. The second factor was whether students engaged in manipulation of story objects (simulation) compared to reading alone (no simulation).

EMBRACE System

Two texts were used within EMBRACE in this study. The narrative text, called "The Best Farm," consists of seven short chapters with a total of 838 words. The Flesch-Kincaid reading level is grade 2.6. The fictional story uses fun farm characters competing for the "Best Farm Award" to emphasize the importance of cooperation in achieving goals. The expository text, called "The Circulatory System," consists of five chapters with a total of 705 words (see Figure 1). The Flesch-Kincaid reading level is grade 4.9. The exposition describes how the heart and lungs work to keep us alive.

The texts were delivered to children using EMBRACE, an iPad application implemented in Objective-C. When using EMBRACE, children select a story to read from a library of stories, and then read each story chapter by chapter. The first story read by the child includes an introduction to EMBRACE. For successive stories (both narrative and expository), EMBRACE reads the first chapter aloud to the child, by playing pre-recorded audio files. Subsequent chapters are read aloud solely by the child. EMBRACE functions as an e-reader, and individual stories are represented as a combination of .html files, image files, audio files, and .xml configuration files. This separation of content and functionality enables the easy addition of new stories.

Insert Figure 1

Simulation. As in a regular book, chapters of a story consist of several pages with images representing the story content covering the bulk of the screen and text in the top right (see Figure 1). Students tap a “Next” button to move from sentence to sentence. Upon tapping “Next”, the just-read sentence is dimmed and the to-be-read sentence is colored in blue or black font, depending on whether it is an **action sentence** (blue), or a **non-action sentence** (black). For non-action sentences, no simulation is prompted. Children read a sentence, and then tap the “Next” button to move to the next sentence.

For action sentences, children read the sentence and then perform the action specified in the sentence using the story image. For example, they might read in the expository text, “When the heart beats, the blood rushes through the arteries to the muscles, ” and move the blood cell with an oxygen molecule (two red, adjacent circles) from the ventricle, through the artery, to the muscle in the arm. Children touch an image to select it and drag it over to the desired position. Some sentences require several movements; for example, the sentence, “The farmer took the hay into the barn,” would first require the child to move the farmer to the hay. The application groups the farmer and the hay, and then the child must move the grouped farmer and hay objects into the barn (as though the farmer was carrying the hay). There are also some sentences for which the application prompts the child to disambiguate between two possible relationships between objects. For example, in the above sentence when the farmer is moved to the hay, the child selects between two menu options, one where the farmer is holding the hay, and one where the farmer is standing on top of the hay. Once the child is done with the simulation required by the sentence, the child taps the “Next” button.

EMBRACE functions as a limited intelligent tutoring system (VanLehn, 2006), in that feedback is provided to children on each step. If children move the wrong image, or move an image to the wrong place, a warning noise is played, and the image is snapped back to its original location. A warning sound is also played if the child taps the “Next” button before successfully simulating the sentence. To achieve this functionality, the steps within the application performed by the children are compared to ideal solution steps encoded in the .xml metadata files included with the story.

Spanish support. Spanish support is provided in several ways:

1. *Vocabulary page provided in Spanish and English.* Each chapter begins with a list of important vocabulary words found in the chapter. These words are presented in both English and Spanish. The child must tap on the Spanish word to hear the Spanish pronunciation, definition, and where possible, see the corresponding image highlighted. The child then taps on the English word to hear the English pronunciation, definition, and see the corresponding image highlighted.

2. *Vocabulary help provided in Spanish and English.* While the child is reading each chapter, some important or difficult words in the text are underlined. To get help, the child taps on each underlined word to hear the Spanish and English pronunciation, and where relevant, see the corresponding image highlighted (see Figure 1).
3. *First chapter read in Spanish.* The first chapter is read to the child in Spanish, rather than in English. The point of reading the first chapter aloud is to provide the child with relatively easily accessible background information that might be useful in reading and comprehending the remaining chapters. Thus, reading the chapter aloud in the child's native language might better prepare the child for subsequent chapters.

Control versions of EMBRACE. To understand the effects of the simulation and dual language support, we implemented several control versions of EMBRACE. In no-simulation versions of EMBRACE, students still tap "Next" to move from sentence to sentence, and the current sentence is still colored blue or black, depending on whether it is an action sentence or a non-action sentence. However, children cannot manipulate the images related to the story. For action sentences, children are told by EMBRACE, "When a sentence is blue, it is an important sentence. After reading the sentence out loud, be sure to think about what it means." Children still receive vocabulary help before each chapter, and can still tap on words to receive pronunciation on demand. In the Englishversions of EMBRACE, students still see the vocabulary page prior to each chapter, but words are repeated twice in English, rather than presented in English and Spanish. While reading, children can still tap on a word to hear it pronounced and see the corresponding image highlighted, but words are pronounced twice in English. The first chapter of each story is read out loud to the child in English, not Spanish.

Participants

Participants were 93 children enrolled in extracurricular programs at two schools, three community centers, and one library. Teachers and program administrators selected all children to meet the following criteria: (a) attending grades 2-5 (one child in the first grade was referred to the project, but this child did not meet other criteria listed below, so data were not included in the analysis), and (b) classified as Spanish-speaking DLLs. Participants were randomly assigned to one of four conditions: simulation+Spanish support, simulation+English, control+Spanish support, and control+English. As the intervention was designed for Spanish-speaking children who have some ability to decode in English, we eliminated all children from analysis who, (c) scored below 21 on the decoding portion of the Qualitative Reading Inventory – 5th edition (QRI; Leslie & Caldwell, 2010), and (d) scored less than 3 on the Spanish portion of the Spanish-English Language Proficiency Scale (SELPS; Smyk, Restrepo, Gorin, & Gray, 2013). These scales are described below in the "Measures" section. Finally, we only report data from children who participated in at least 75% of the intervention. Applying these three criteria reduced the number of children contributing data from the narrative text to 70 and the number of children contributing data from the expository text to 63. Table 1 shows characteristics of children retained for analyses.

Insert Table 1

Procedure

Day 1. All data were collected individually with one child assigned to one experimenter (although the experimenter varied over the course of data collection). The Day 1 procedure was the same for all conditions. After obtaining the child's assent, the child was given both English and Spanish versions of the SELPS in a random order with the constraint of availability of a Spanish-speaking experimenter. Next, the QRI was administered. At the end of each session, children received stickers as rewards.

Day 2-5. The procedures for Days 2-5 depended on the child's randomly assigned condition. On Day 2, the children were introduced to EMBRACE. Each sentence in the introductory text was read aloud by the application. During the introductory text, the child was instructed by EMBRACE on three activities. First, the child was instructed to read each sentence aloud along with or following the iPad. In addition, the child was instructed on how to proceed from one sentence to the next by tapping the "Next" button. Second, the child was instructed on how to tap a word to hear it pronounced (and see the picture highlighted if the word corresponded to a visible picture). In the simulation conditions, the child was instructed on how to move pictures to simulate a sentence when the sentence was presented in a blue font. In the Spanish support conditions, the three components of the instructions were first explained (by the application) in Spanish, and then further instruction was given in English. In the English conditions, instructions were given in English.

On Days 2 and 3, students read "The Best Farm" using whichever version of EMBRACE mapped to their condition. Each chapter was followed by a comprehension test administered by the experimenter. Following the last chapter, the child was instructed by the experimenter, "Please tell me the whole 'Best Farm' story starting with the first chapter that was read to you." Following this recall, the child was given chapter-by-chapter prompts for additional recall, such as "Can you remember anything else from the first chapter, 'The Contest?'...Can you remember anything else from the chapter, 'Getting Ready?' ". On Days 4 and 5, the child read the expository text about the circulatory system using EMBRACE, and took a comprehension test after each chapter. Following the comprehension test for the last chapter, the child was asked to recall as much of the information as he or she could remember and then was given chapter-by-chapter prompts. The recall data were near the floor (perhaps because children were tired after a day at school and participation in the experiment), and so these data are not reported.

Measures

SELPS (Smyk et al., 2013). The SELPS is designed to measure the level of oral language proficiency in bilingual children 5 to 8 years old. The test uses modifications of the wordless storybooks *Frog on his Own* (Mercer Mayer, 1973) and *A Boy, a Dog, a Frog, and a Friend* (Mercer Mayer & Marianna Mayer, 1971). The child looks at the pictures while listening to an oral telling of the story in either Spanish (for *A Boy, a Dog, a Frog, and a Friend, Un Pino un Perro una Rana y un Aamigo)* or English (*Frog on his Own*). Immediately after listening, the child retells the story in the same language. The retellings are scored on 4 domains: syntactic complexity, grammatical accuracy, verbal fluency, and lexical diversity. Each domain is scored between 1 and 5 according to how well the child can speak the target language, and the SELPS total score is the sum of scores obtained in the domains. The mean score (reported in Table 1) is used to classify the participant as high proficiency (4-5), medium proficiency (2.5-3.5), or low proficiency (1-2). The sample for standardization included 500 Latino children in the Phoenix metropolitan area.

QRI (Leslie & Caldwell, 2010). The QRI is an informal reading inventory designed to give information about how a child decodes and comprehends text. Only the word reading ability portion was used to screen out children who were poor decoders. Children attempted to read aloud 40 English words from the QRI. We recorded whether

a) a child was able to easily decode the word, b) required some time or sounding out, or c) could not decode the word. The decoding variable used in the statistical analyses (and reported in Table 1) consisted of the total number of words in categories a and b. Children needed to be able to read (fluently or sound out) more than half of the words to be retained in the sample.

Comprehension assessment. Each chapter was followed by 5-7 comprehension questions. The questions were open-ended (e.g., "Which animal jumped into Manuel's arms?" "How many atoms does an oxygen molecule have?"), however, if the child did not answer correctly, the child was asked to choose between two options (e.g., "Did the cat or the chicken jump into Manuel's arms?" "Does an oxygen molecule have 1 or 2 atoms?"). Each story included questions that probed for verbatim information (as above) or for inferences. For example, in Chapter 3 of "The Best Farm," the farmer falls and needs to stay in bed for the rest of the week. An inference question was, "At the end of the story, how did Manuel feel?" If the child did not answer correctly, the two options were, "At the end of the story, was Manuel hurt or was Manuel happy?" Children were awarded two points for correctly answering the open-ended question or one point for selecting the correct option from the two offered. We computed the proportion of verbatim questions the child answered correctly and the proportion of inference questions the child answered correctly for each story. In our reporting of the results, we exclude questions from Chapter 1 of both texts because those chapters were read to the children by the application and because some students answered those questions in Spanish and others in English.

Log data. All data from use of the application were logged, including student actions (selecting objects, moving objects to other objects, tapping on words) and computer responses (assessing each action as correct or incorrect). From log data, we can get information about how children were using the application and why particular features of the application might have benefits. For example, examining help requests, or when children tap on words to request pronunciation help, can provide insight into how the different conditions influenced help-seeking behaviors.

Results

Effects of Condition on Reading Comprehension

Our first analysis addresses RQ1a ("*Does simulation practice improve DLL reading comprehension of narrative texts over traditional reading practice?"*) and RQ2a ("*Does Spanish support enhance the effects of simulation to improve DLL reading comprehension of narrative texts over traditional reading practice?"*). We conducted a two-way MANOVA with proportion of inference questions correct and proportion of verbatim questions correct in the narrative text as dependent variables, and simulation and language as independent variables (see Table 2 for means and standard deviations). With respect to the overall model, simulation has a significant effect [F (2,65) = 8.77, $p <$ 0.001], whereas language does not [F (2,65)= 0.052, p = 0.95]. The simulation x langauge interaction was not significant [F (2,65)=0.338, p = 0.715]. Examining the effects of simulation on each dependent variable, we see that it improves reading comprehension scores on both inference questions [F (1,66) = 16.30, p < 0.001] and verbatim questions [F (1,66) = 8.87, p = 0.04].

We then investigated RQ1b ("*Does simulation practice improve DLL reading comprehension of expository texts over traditional reading practice?"*) and RQ2b ("*Does Spanish support enhance the effects of simulation to improve DLL reading comprehension of expository texts over traditional reading practice?"*) by conducting a two-way MANOVA with proportion of inference and verbatim questions correct in the expository text as dependent variables, and simulation and langauge as independent variables. Means and standard deviations are reported in Table 2. We found no significant effects of simulation [F (2,58) = 0.819, p = 0.446], language [F (2,58) = 0.242, p = 0.786], or the interaction [F (2,58) = 0.935, p = 0.675].

The above analyses suggest that while simulation enhanced comprehension of the narrative text, it did not have a similar effect on the expository text, and Spanish support did not have the hypothesized effects. The expository text had a higher reading level than the narrative texts (grade 4.9 vs grade 2.6), and, children scored much lower on the comprehension questions for the expository texts. It might be that a child's existing comprehension abilities moderated the effects of the simulation intervention on reading comprehension. In addition, our literature review of the potential positive effects of Spanish support, presented above, would suggest that prior decoding ability and English language ability might all play a role in the degree to which the child benefits from the combination of reading ability and Spanish support.

Insert Table 2

The Influence of Prior Knowledge on Reading Comprehension within EMBRACE

To explore the potential role of prior language ability in more depth, we used multi-level modeling to investigate interactions between children's prior language abilities and the features of our interventions. For each of the two texts, we fit models to two dependent variables: the proportion of post-chapter inference questions answered correctly and the proportion of post-chapter verbatim questions answered correctly, mirroring the analysis above. Because of the large number of statistical tests, we reduced the probability of Type 1 errors by using a conservative .01 significance level. The multi-level modeling allowed us to a) model the effects of decoding (measured using the QRI) and English language skill (measured by the English SELPS) as continuous variables, and b) to use tests of significance of embedded models to reduce the number of parameters needed to be estimated. If a model with a greater number of parameters did not provide a significantly better fit, then those parameters were not analyzed in detail.

For each text and for each dependent variable, we started with a base model that included the intercept, language (English or Spanish support), manipulation (no-simulation or simulation), and the language x manipulation interaction. These variables were dummy coded and mean centered. The next model included decoding (mean centered), the interactions of decoding with language, manipulation, and the three-way interaction, that is, an additional four parameters. The next model included the mean-centered English SELPS score and its interactions for eight more parameters.

Insert Table 3

Table 3 provides the model fits in terms of "deviance" or -2 * log likelihood. The difference in deviance between two embedded models is distributed as a chi-square statistic with degrees of freedom equal to the difference in number of parameters. Differences in models significant at the .01 level are highlighted. Thus, for the narrative inference question analysis, we report data corresponding to the base model. That is, none of the other models provided a statistically significant better fit. For the narrative verbatim question analysis, we report data corresponding to the base model plus decoding and English SELPS and all of their interactions. For the expository inference questions, we use the base model, and for the expository verbatim questions we use a model including decoding.

Table 4 shows the t-values associated with the significance tests for the parameters in the best fitting models (from Table 3). Significant t-values are highlighted. Finally, Table 5 contains the estimated means (and standard errors) for the significant effects (from Table 4). As recommended by Aiken and West (1991), the means for a low-level of a continuous variable (e.g., decoding or English SELPS) were estimated at one standard deviation below the mean value, and the means at a high-level were estimated at one standard deviation above the mean. However, for high decoding, we used the maximum score, 40, which was a bit less than one standard deviation above the mean.

Insert Tables 4 & 5

Results from the base model for "The Best Farm" narrative text inference questions are equivalent to the inference results from the MANOVAs above (see Table 2). When reading a narrative at grade level and answering inference questions, simulation shows a clear benefit compared to the no-simulation condition. The difference between the means corresponds to a Cohen's *d* effect size of .77. That is, simulation helps these children to understand the meaning of the text and make accurate inferences.

The data are more complicated when considering performance on the Best Farm verbatim questions (Table 5, Section A). That is, there is a significant four-factor interaction involving manipulation, language, decoding, and English SELPS. Starting with children who are both poor decoders and deficient in English language skills, we see that neither simulation nor Spanish support is particularly helpful. For children who are good decoders, but deficient in English language skills, the combination of simulation and Spanish support is particularly helpful (increasing performance from an average of 85% to 96% correct). Similarly, for children who are poor decoders but have good English language skills, the combination of simulation and Spanish support is again helpful (increasing performance from 81% to 95% correct). Finally, for children who are both good decoders and have good English language skills, they do relatively well in all conditions. In summary, simulation combined with Spanish support can make up for one deficit (in decoding or in English language skills), but not both, when it comes to learning the verbatim details of narrative texts read in English.

The expository text, which was written at about two grade levels above the average grade-level of these children, was a challenge. Children answered correctly only 49% of the inference questions, and none of the manipulated variables made a significant difference. However, for the verbatim questions, there was a significant interaction between decoding and manipulation (see Table 4). As the data in Table 5, Section B indicate, for the good decoders, simulation improved performance with d = .83. However, for the poor decoders, simulation was not effective.

To summarize, the above analyses suggest three main results. First, simulation improves reading comprehension performance on narrative texts. For more challenging expository texts, simulation is most effective at improving reading comprehension for good decoders, but does not yield the same benefits for poor decoders. Finally, for either good decoders or students with strong English language skills, the combination of simulation plus native language support can also improve performance.

Insert Table 6

Intervention and Use of the Application

To help interpret the above results, we turn to the log data. As described above, we collected information about a variety of children's actions within the application. Here, we examine the mean number of help requests per chapter students made by tapping on words as they were reading texts. Exploring how simulation, Spanish support, and prior knowledge interacted to influence help requests might facilitate interpretation of the comprehension results. As above, we exclude data from the first chapter. In addition, there was an implementation error that led to missing log data. We excluded all participants with less than 75% complete log data, removing an additional 8 participants for "The Best Farm" and 9 participants for "The Circulatory System".

Our analysis uses a mixed model approach akin to the one presented above. We fit models to each of the two texts, and for each text, investigate one dependent variable: help requests made per story. As above, we started with a base model that included the intercept, language (English or Spanish support), manipulation (no-simulation or simulation), and the language x manipulation interaction. The next model included decoding (mean centered) and the interactions of decoding with language, manipulation, and the three-way interaction. The next model included the mean-centered English SELPS score, and all interactions. Table 3 presents the deviances for each of the models (under the "Help" column), and differences in models significant at the .01 level are highlighted. Thus for both the narrative text and expository text, we report data from the base model plus decoding.

The t-values for the best fit models can be found in Table 4, again under “Help.” For the narrative text, only decoding ability is significant at the $p < 0.01$ level. Means and standard errors can be found in Table 6. Low decoders request more help than high decoders. There is a trend ($p = 0.07$) for those in the simulation condition to request less help than those in the no-simulation condition, and also trend towards an interaction ($p = 0.07$), where low decoders in the no-simulation condition request the most help. For the expository text, both language and decoding are significant at the $p < 0.01$ level, with students in the English condition requesting more support, and low decoders requesting more support. In addition, there is a trend towards a manipulation X decoding interaction ($p = 0.013$). Low decoders in the no-simulation condition still request a lot of help, but low decoders in the simulation condition request the most help. Similarly, low decoders in the English condition request a large amount of help compared to low decoders in the Spanish support condition ($p = 0.022$).

To summarize, it appears that help requests are used by students to extract more support from the application. Across both texts, low decoders, students who do not receive Spanish support, and students who do not participate in simulation request more help. One exception is low decoders in the simulation condition for the expository texts, who may, in fact, require more help to perform the simulations in the more complex text. In the narrative text, average help requests are negatively correlated with verbatim proportion correct ($r(60) = -0.517$, $p < 0.001$) and with inference proportion correct ($r(60) = -0.317$, $p = 0.012$). In the expository text, average help requests are negatively correlated with verbatim proportion correct ($r(52) = -0.287$, $p = 0.035$), although not with inference proportion correct ($r(52) = 0.046$, $p = 0.743$). Requesting more help appears to be a sign that students are not receiving enough support within the application.

Discussion

Our first research question (RQ1a) was whether simulation can be an effective strategy for increasing narrative reading comprehension for Latino DLL children. When children were reading in English a grade-appropriate narrative, there was a clear benefit of simulation, with $d = .77$. This result was found for both inference questions and verbatim questions. On the surface, the large benefits of simulation for DLL children contradict the recent findings of Takacs et al. (2015) in a meta-analysis of the effects of interactive features on listening comprehension. Takacs and colleagues found that interaction generally reduced benefits that accrued to electronic multimedia compared to listening to traditional oral narration. The effect of interaction was particularly deleterious for children classified as "disadvantaged," because of low socioeconomic status, bilingual immigrant families[1], and children with learning problems of various sorts. Why should Takacs et al. find that interaction is deleterious, whereas we find large benefits? One possibility is the difference between listening comprehension and reading comprehension. However, a more plausible explanation trades on the definition of "interaction" (Bus, Takacs, & Kegel, 2015).

In the Takacs et al. (2015) study, interaction features included a) hotspots that when touched might produce a sound associated with the image, b) dictionaries, c) games, and d) questions. They suggest that at least some of these interactions are not "tightly connected to the storyline" (p. 4). In the EMBRACE system, interaction corresponds to simulation, which is tightly integrated with the storyline. Simulation is imagination (although not always conscious imagination) of text content. The current research

[1] To be clear, we do not view bilingualism as a disadvantage, although it may temporarily slow some aspects of language development. However, we will occasionally use this term when referring to some of Takacs' analyses, as it is the term they used.

findings support the idea that teaching young children to simulate may well be a step in promoting strong reading comprehension.

Our second research question (RQ1b) was whether simulation was useful when the children read expository texts. Here, we found that the effects of simulation interacted with the child's decoding ability. For good decoders, simulation improved performance on questions targeting verbatim information, but not for inferential questions. It is possible that this finding is due to the difficulty of the text. For this text, children were faced with a significant decoding challenge, and previous work (e.g., Levin, 1973) has demonstrated that comprehension strategies are not effective when decoding is poor. In this case, the children were reading a text that was approximately two grades above their own, and their experiences with expository texts at this age are limited. Finding any benefits of a reading comprehension strategy might be seen as impressive.

RQ2a and RQ2b investigated whether native language support, in this case, Spanish, provided benefits in comprehension when used with simulation. For poor decoders who also had difficulty with the English language (i.e. low English SELPS), Spanish support did not seem to help comprehension. Conversely, for good decoders who also had strong English language skills, Spanish support did not help much, probably because these children were already understanding the narrative text well. The findings were different for children in the middle. Consider first the children who were relatively poor decoders but otherwise had strong English language skills. Combining simulation with Spanish support helped these children to comprehend and remember verbatim details. One interpretation of this result is that when the child was unable to read some proportion of the words, there was a reduction in the ability to answer verbatim questions. The Spanish support helped these children to decode some of the words with meaning (hearing the words in Spanish when they tapped on underlined vocabulary words). Then, their strong English abilities, further enhanced by simulation, helped the children to excel. A similar type of compensatory explanation can be proposed for children who were relatively good decoders, but had poor English language skills. These children were able to pronounce the words in English, but had limited access to the meaning after pronunciation. For these children, simulation helped them to consider the meaning of the text, and this was particularly useful when they used sensorimotor experiences prompted by Spanish support (i.e. sensorimotor experiences associated with Spanish words; Jared, Pei Yun Poh, & Paivio, 2013).

This analysis is corroborated by the pattern of support requested by children using the application. As is to be expected, poor decoders tended to request more pronunciation help from the application than good decoders. However, we further found evidence that students who were not engaged in simulation and students who did not receive Spanish support requested more help. Help requests were negatively correlated with children's reading comprehension scores across both texts. It appears that both simulation and Spanish support provided assistance to students that reduced their need to request help within the application, providing further evidence of the promise of this approach.

We conclude by answering the questions implied by the title of this article. *When* young children are reading grade-appropriate texts written in a familiar narrative style, interaction, in the form of simulation of text content, helps comprehension. *Furthermore, when* reading an advanced exposition, decoding ability plays an important role. Namely, good decoders are helped by simulation, whereas poor decoders are not. *How* does simulation help? We believe that it induces children to engage in the sort of embodied processing that is necessary for language comprehension.

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Table 1

Mean (SD) of characteristics of children assigned to four conditions, Spanish support + simulation, simulation only, Spanish support only, and no-Spanish support, no-simulation

Condition	n	Age in months	English SELPS	Spanish SELPS	QRI Decoding
	Narrative text (Best Farm)				
No Simulation+English	18	99.9 (11.9)	4.5 (.5)	4.2 (.8)	34.9 (5.3)
Simulation+English	17	100.5 (16.2)	4.7 (.4)	4.2 (.8)	36.9 (4.8)
No Simulation+SS	18	95.1 (11.1)	4.5 (.5)	4.3 (.7)	34.4 (5.4)
Simulation+SS	17	103.6 (12.8)	4.6 (.5)	4.3 (.7)	37.5 (4.0)
	Expository text (Circulatory System)				
No Simulation+English	17	100.5 (12.0)	4.5 (.5)	4.3 (.8)	34.9 (5.5)
Simulation+English	14	103.3 (14.8)	4.7 (.5)	4.1 (.8)	37.6 (4.0)
No Simulation+SS	15	95.9 (11.0)	4.5 (.5)	4.4 (.6)	33.8 (5.7)
Simulation+SS	17	103.6 (12.8)	4.6 (.5)	4.3 (.7)	37.5 (4.0)

Note: SS = Spanish support

Table 2

Mean percent correct (SD) for effects of condition on reading comprehension

		Narrative Text (Best Farm)		Expository Text (Circulatory System)	
		Inference	Verbatim	Inference	Verbatim
No-Simulation	English	82 (12.55)	84 (9.18)	46 (14.50)	54 (10.44)
	Spanish support	82 (11.29)	82 (9.04)	47 (15.08)	50 (10.45)
Simulation	English	92 (12.55)	89 (8.15)	45 (10.82)	56 (14.96)
	Spanish support	91 (8.19)	90 (9.00)	48 (12.68)	57 (16.31)

Table 3

Model fits for reading comprehension questions and help requests (deviance values and chi-square tests*)

Model	Narrative Text (Best Farm)			Expository Text (Circulatory System)		
	Inference	Verbatim	Help	Inference	Verbatim	Help
Base Model	519.853	499.965	185.869	501.947	500.723	317.320
With Decoding (4 additional parameters)	507.471	**468.416**	**149.494**	495.206	**482.022**	**283.070**
With English SELPS (8 additional parameters)	496.418	**445.870**	143.864	476.163	474.126	272.57

*With 4 (8) additional parameters, the reduction in deviance must exceed 13.28 (20.09) to be a significant improvement in fit at $p < .01$. Bolded values indicate a significant reduction in deviance.

Table 4

T-values for Best Farm (narrative) and Circulatory System (expository) parameters.

	Narrative text (Best Farm)			Expository text (Circulatory System)		
Parameter	Inference (70 df)	Verbatim (70 df)	Help (62 df)	Inference (63 df)	Verbatim (63 df)	Help (54 df)
Language (L)	-0.17	1.33	.001	0.52	-0.52	**-2.94**
Manipulation (M)	**4.16**	1.47	-1.83	-0.07	0.14	1.65
L x M	-0.349	2.06	.597	0.25	1.11	-1.14
Decoding (D)		**4.76**	**-4.31**		**3.99**	**-6.71**
D x L		-.056	-0.280		-0.33	2.35
D x M		1.26	1.827		**3.47**	-2.57
D x L x M		-1.84	0.814		0.28	1.56
SELPS (S)		**2.80**				
S x L		0.50				
S x M		-0.23				
S x D		-0.43				
S x D x L		-1.91				
S x D x M		0.55				
S x D x L x M		**-3.18**				

Note: Values significant at $p<=.01$ are bolded.

Table 5

Estimated mean percent correct (SE) for significant effects*

A: Best Farm Verbatim Questions		
Low Decoding; Low English SELPS	English Only	Spanish Support
No Simulation	79 (2.0)	76 (2.0)
Simulation	80 (2.5)	79 (2.8)
High Decoding; Low English SELPS		
No Simulation	87 (2.6)	84 (2.9)
Simulation	84 (6.4)	96 (4.0)
Low Decoding; High English SELPS		
No Simulation	88 (3.6)	82 (2.9)
Simulation	74 (6.0)	95 (4.7)
High Decoding; High English SELPS		
No Simulation	87 (2.7)	92 (3.1)
Simulation	97 (2.7)	92 (2.3)

B: Circulatory System Verbatim Questions		
	Low Decoding	High Decoding
No Simulation	51 (2.3)	41 (4.0)
Simulation	53 (2.8)	62 (2.4)

- Low indicates that means were estimated at 1SD below the mean of the factor (e.g., below the mean Decoding Score) and High indicates that means were estimated at 1 SD above the mean of the factor

Table 6

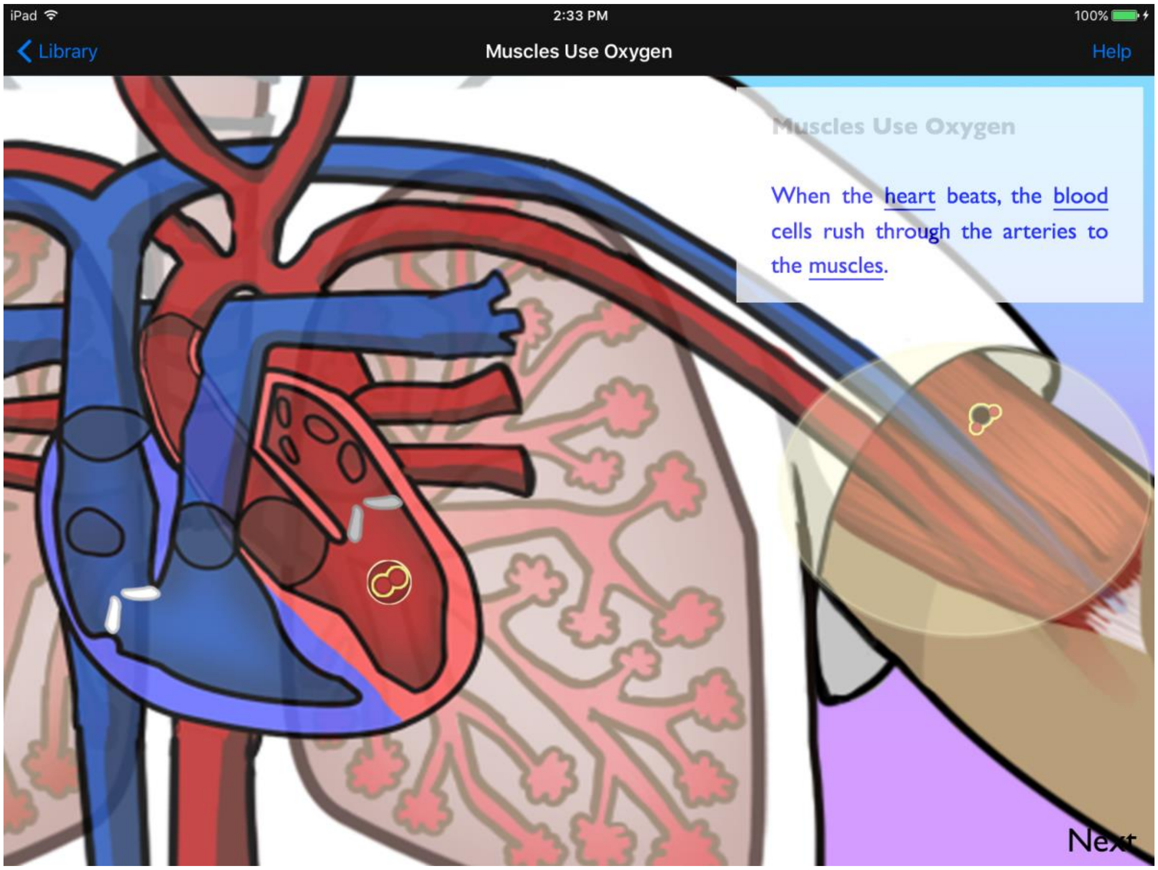
Estimated mean (SE) help requests per problem. Negative values indicate a high proportion of 0 requests for that particular group. SS = Spanish Support

		Best Farm		Circulatory System	
		Low Decoding	High Decoding	Low Decoding	High Decoding
No-Simulation	English	1.365 (0.24)	-0.057 (0.30)	7.71 (1.14)	1.713 (1.21)
	SS	1.796 (0.23)	-0.249 (0.31)	4.89 (1.21)	0.894 (1.59)
Simulation	English	0.753 (0.81)	-0.077 (.33)	15.47 (2.56)	-0.497 (1.39)
	SS	0.409 (0.39)	-0.025 (.28)	2.92 (2.49)	0.184 (1.21)

Figure Captions

Figure 1. Screen shot from one chapter in the Circulatory System expository text. The child has tapped the underlined word “muscle.” The iPad plays a sound file providing the pronunciation of the word in English (and in Spanish in the Spanish support condition), and as illustrated, the image of a muscle in highlighted. To complete the manipulation, the child moves the oxygenated blood cell (circle containing two red circles) in the heart through the red artery to the muscle in the arm.

Figure 1


iPad
2:33 PM
100%
Library
Muscles Use Oxygen
Help
Muscles Use Oxygen
When the heart beats, the blood cells rush through the arteries to the muscles.
Next