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Opening the Black Box:

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Opening the Black Box: User-Log Analyses of Children's e-Book Reading and Associations with Word Knowledge

Strategic reading and effective reading comprehension require a broad range of word knowledge, including context-free word recognition and understanding words in context (Perfetti & Stafura, 2014; Sénéchal & Cornell, 1993; Tannenbaum, Torgesen, & Wagner, 2006). Students' deep word knowledge is an essential component in comprehending text (Kim, 2016; McNamara & Magliano, 2009; Perfetti, 2007). As children learn new vocabulary words and begin to use them in context, they also learn to comprehend sentences and make connections between multiple sentences and paragraphs (Kintsch, 2005; Oakhill & Cain, 2004). One frustration in assessing reading comprehension is that most assessments (except eye movement tasks) only provide us with post hoc evaluations. Students typically finish reading and then perform tasks designed to assess their reading comprehension (Keenan, Betjemann, & Olson, 2008). However, user-logs generated from e-Books have the potential to assess how students are reading and comprehending text in real-time by providing us with data regarding time spent on pages and how they may attend to difficult passages. Therefore, this study examined student user-logs from an effective e-Book intervention, the Word Knowledge e-Book (WKe-Book; Authors, 2019), to both elucidate how user-logs may offer insights into how children read and how their reading behaviors may be associated with gains in word knowledge. Reading the WKe-Book, an interactive fictional e-Book, was found to be effective in improving third through fifth grade students' word knowledge, word knowledge calibration, and strategy use, in the context of a randomized controlled trial.

Theoretical Framework

Readers engage in numerous processes as they navigate a text. They adopt standards of coherence, or implicit and explicit criteria that reflect their desired level of understanding. These standards influence the dynamic pattern of automatic and strategic cognitive processes that take place during reading (van den Broek, Bohn-Gettler, Kendeou, Carlson, & White, 2011). One's ability to comprehend text is influenced by characteristics of the text (e.g., topic, layout of the text) and the individual characteristics of the reader (e.g., background knowledge, working memory capacity; McNamara, Ozuru, & Floyd, 2017; McVay & Kane, 2012; Rand Study Group & Snow, 2001). According to the theory of standards of coherence, readers may not always be aware of the standards they employ while reading a text, as these standards are often automatic. When these standards are not met, strategic processes (e.g., decoding, morphemic analysis, context clues) may be employed to aid in comprehension. Thus, it is important that students are taught effective reading strategies to keep in their "toolbox" to employ when their standards of coherence are not met (van den Broek, Rapp, & Kendeou, 2005). The WKe-Book intentionally used difficult vocabulary to trigger students' need to employ targeted reading strategies to repair their understanding of challenging text.

While reading difficult texts, effective strategy use helps students determine the meaning of unfamiliar words and make appropriate inferences (e.g., Graves, Ringstaff, & Flynn, 2018). Teaching students reading comprehension strategies is effective in improving comprehension, especially for struggling readers (McNamara, O'Reilly, Best, & Ozuru, 2006). Additionally, teaching strategies in the context of specific texts has been found to be more effective than teaching strategies in isolation (McKeown, Beck, & Blake, 2009). Strategies allow students to monitor their comprehension and repair their misunderstanding, and include finding main ideas (Jenkins, Heliotis, Stein, & Haynes, 1987; Stoeger, Sontag, & Ziegler, 2014), summarization

(Berkeley, Mastropieri, & Scruggs, 2011; Bransford, Brown, & Cocking, 2000), generating questions (Rosenshine, Meister, & Chapman, 1996; Joseph, Alber-Morgan, Cullen, & Rouse, 2016), and word learning strategies (Honig, Diamond, & Gutlohn, 2013; NICHD National Reading Panel Report, 2000). Word learning strategies are those that students can use to figure out the meaning of unfamiliar vocabulary in text to facilitate comprehension. Strategies include using the dictionary, contextual analysis, and morphemic analysis (NICHD National Reading Panel Report, 2000). Providing young readers scaffolded reading experiences should enable them to acquire and utilize word-learning strategies (Authors, 2019). The WKe-Book was designed to consider these strategies, and user-logs may provide us with deeper insights into their manifestation.

Reading motivation, including self-efficacy, interest, and attitudes toward reading, may also influence standards of coherence, affecting how much readers invest themselves in the text (Schiefele, Stutz, & Schaffner, 2016; Wigfield & Guthrie, 1997). For example, motivation may influence how readers respond to challenging texts, depending on their self-efficacy and interest in figuring out the meaning of difficult words. In the WKe-Book, students were able to name their own characters and choose their own adventure. These types of affordances were included in the WKe-Book in order to increase motivation and engagement.

User-log Data

In technology-assisted learning (e.g., the WKe-Book tools), computers can track the steps taken in the learning process. This information is stored in user-logs, which provide an efficient way to examine behaviors that are otherwise difficult to obtain using traditional methods (e.g., think-aloud approaches). Analyses of user-logs allow for investigating reading fluency, persistence in problem solving, and differences in how students navigate the text (Baker, 2010).

To date, only a small body of research has utilized user-logs to examine the associations between reading behaviors and performance on reading comprehension assessments. These studies have mostly focused on reading time, with conflicting results of the relation between reading time and performance. Increased reading time may positively relate to the learning outcome if the reading task is cognitively demanding (Topping, 2018). However, faster reading may also be an indicator of processing text more fluently and reflect higher skill (PISA, 2014). Regarding these contradictory findings, Goldhammer and colleagues (2014) suggested that the complex relation between reading time and performance may depend on the reader's ability and the text difficulty. Reading simpler text quickly may reflect strategic reading that typically supports comprehension, whereas the same reading behavior in more difficult texts may be less adaptive in comprehension. Furthermore, as reading is a contextualized activity, it is important to make the distinction between text-based importance and task-based importance. Text-based importance refers to the degree to which a text segment includes information needed to understand the text, whereas task-based importance refers to the extent to which a segment contains information related to a task, such as answering a question (Rouet & Britt, 2011). Depending on the context, readers may switch from a "default" processing strategy based on textual importance to a task-based strategy in which they focus on text segments that are relevant to the task. In the WKe-Book, we can investigate this further by having access to reading time on text-only pages and on question pages that differ in the required metacognitive skills and motivation to comprehend each type of page.

In addition to studying the time spent on reading, another line of research has utilized user-log data to examine students' decision-making when they are allowed to select different reading sections through clicking links, a common feature of e-Books (Naumann, 2015,

Shimada, Taniguchi, Okubo, Konomi, & Ogata, 2018, Villagrá-Arnedo et al., 2017). Because such reading requires readers to make decisions (i.e., prospective reasoning; Chernyak, Leech, & Rowe, 2017), it may require more attention than traditional linear reading materials where the content is predefined. Studies have found that students who make thoughtful decisions while navigating linked reading sections are typically better comprehenders than those who click on links without any apparent rationale (e.g., Naumann, 2015; Salmerón & García, 2011). For example, Salmerón and García (2011) found that students who selected reading sections semantically related to the previously read material scored higher in inferential comprehension measures than students who followed less cohesive routes. While previous studies have investigated decision-making in informative texts, the WKe-Book considered decision-making in a narrative text, thus allowing us to examine if the relations between strategic decision-making and learning occur in a different genre. Additionally, while most of these studies demonstrate the utility of user-logs in understanding how students interact with text, the majority of them have focused on adolescents. Considering the lack of previous research examining user-logs of younger readers, this study aimed to examine students in third through fifth grade.

E-book Affordances for Teaching Reading Strategies

E-Books provide technological enhancements that make the reading experience qualitatively different from traditional paper books. One enhancement is the inclusion of interactivity, where readers can receive immediate feedback on what they do (Moreno & Mayer, 2007; Piotrowski & Krcmar, 2017). A large body of research has investigated whether such interactivity is beneficial to reading comprehension, with results mixed depending on multiple factors including the design of interactive features (Takacs, Swart, & Bus, 2015). In general, interactive elements that are tightly connected to the storyline facilitate children's

comprehension, while those that are extraneous do not benefit, or may even impede, learning. Dictionary access and embedded comprehension questions with immediate feedback are two interactive features that have been found to support the development of word learning and reading comprehension (Bus, Takacs, & Kegel, 2015; Roskos, Brueck, & Lenhart, 2017; Scoter, 2008) and scaffold the use of reading strategies (Caplovitz, 2005; McKenna, Reinking, Labbo, & Kieffer, 1999). For example, a web-based interactive multimedia literacy software was designed to explicitly target reading comprehension strategies and was found to produce positive effects on vocabulary gains and reading comprehension for first and second graders (Lysenko & Abrami, 2014). However, little is known about how students during middle childhood engage with e-Books and what types of behaviors are associated with learning gains. Through analyzing students' user-logs, we aimed to better understand the specific reading behaviors that predicted students' word knowledge gains.

The Word Knowledge e-Book

The WKe-Book, entitled *The Dragon's Lair: The Story of the Scarlett Square* (McDonald, 2012), is a story about a boy and his magical unicorn who go on adventures by picking a square on a counterpane quilt. There are two main characters who the student gets to name. The boy ends up in a village where evil green dragons are kidnapping children and forcing them to work in caves. The boy meets the girl and they end up defeating the evil green dragons and saving the kidnapped children. The WKe-book is a choose-your-own-adventure story that is six chapters long and includes reading comprehension questions embedded in each chapter. The primary goal of the WKe-Book was to improve comprehension monitoring and word knowledge. Therefore, the book deliberately included target words that were unknown to students (third, fourth, and fifth graders), which were embedded in both comprehension questions and on

decision pages. The target words were often chosen from the SAT/ACT Word List. See the appendix for images of the WKe-book.

The Present Study

The user-logs of the WKe-Book offered the opportunity to investigate how students read, inferred the strategies they employed, and how their engagement was associated with their reading comprehension and gains in word knowledge. As discussed previously, students set standards of coherence when reading to aid in their comprehension. However, when these automatic processes do not result in sufficient coherence, reading strategies can be utilized to monitor and repair misunderstanding. Additionally, utilizing certain affordances and features of technology, the WKe-Book was designed to enhance students' use of these reading strategies and increase reading motivation. Through examination of user-logs, we can gain a better understanding of how students interacted with these reading tools and how individual differences and specific reading behaviors related to gains in word knowledge. In this study, we examined third through fifth grade students' (i.e., ages 8 to 10) reading behaviors while reading the WKe-Book and investigated behaviors and beliefs that were associated with reading comprehension and word knowledge. We also investigated how the use of a teacher-led book club, designed to scaffold young readers' use of reading strategies, related to how they read the book and their word learning. More specifically, we sought to answer the following research questions:

1. How did students interact with the WKe-Book descriptively?
    - How much time did they spend reading text-only pages and question pages?
    - How often did they answer questions correctly on the question pages?

- How often did they make poor choices in story stream decisions where only one of the two choices is plausible?

2. How did WKe-Book reading behaviors vary as a function of students' reading comprehension skills?
3. To what extent were students' characteristics (e.g., grade level, prior word knowledge, and word knowledge confidence) and WKe-Book reading behaviors associated with gains in students' word knowledge?
4. To what extent did participation in the book club impact students' WKe-Book reading behaviors and word knowledge gains?

For our second research question, we hypothesized that reading comprehension would positively predict answering embedded questions correctly and making plausible choices on story stream decision pages. For our third question, we hypothesized that answering embedded questions correctly would positively predict gains in word knowledge, whereas making poor decisions would negatively predict gains in word knowledge. For our fourth question, we hypothesized that book club participation would predict gains in word knowledge and lead to more strategic reading indicated by children answering questions correctly more often and avoiding poor decisions (i.e., choosing the implausible option).

Methods

Participants

The participants in the study were 581 third (n=191), fourth (n=182), and fifth grade (n=208) students from 25 classrooms in two schools in South Central Arizona. The sample was 49% female and 67% Hispanic. Approximately 70% of the students qualified for the U.S. National School Lunch Program and 16% of the students were English Language Learners. The

mean age of the students was 9.5 years old. On average, these students were reading at the 30th percentile on the Gates-MacGinitie Reading Test (MacGinitie, MacGinitie, Maria, & Dreyer, 2002), a standardized test of reading. Students were recruited via backpack mail. All students in participating classrooms were invited to participate. Approximately, 96% of students invited participated.

The WKe-Book Intervention

This study was part of a larger study examining the impact of the WKe-Book on gains in word knowledge (Authors, 2019). The study employed a delayed treatment design, where classrooms were randomly assigned to receive the WKe-Book immediately or after the first group completed the book. For this study, we examined user-logs for both the immediate and the delayed treatment groups. In addition, students were randomly assigned within classrooms to one of two conditions: (1) Read the WKe-Book and take part in a weekly book club with other students and a teacher, or (2) to read the book on their own during class time. The WKe-Book was read (possibly multiple times) over a period of three weeks. Students in the first condition were given 30 minutes twice a week to read the WKe-book on their own and then met in the book club with a trained interventionist once a week. Students in condition two were allowed to read the WKe-Book for three days. iPads were provided to the students so they could access the WKe-Book online. They received an introduction to the WKe-Book, information on logging in, and, taught how to use the iPad dictionary. Students who read the WKe-Book before the three weeks ended were instructed to read the story again and select a different story stream.

Trained research teachers facilitated book clubs in groups of five to six students. Classroom teachers were tasked with monitoring the students in condition two (reading the WKe-Book alone) while the interventionist facilitated book club meetings. The book clubs were

focused on teaching the following word learning strategies: using context clues, word history/structure, and dictionary use. For *Context Clues*, students were instructed to read other parts of the text and infer the meaning of the target word. Students were also instructed to consider *Word History/Structure* and how to analyze word parts to figure out the meaning of the word. Word parts that were introduced included common suffixes and prefixes, common roots, and word history. *Using the dictionary* focused on teaching students how to access the iPad dictionary and interpret the definitions. During the book club, students completed worksheets that focused on specific target reading strategies and they discussed the meaning of target words, reading strategies, and how their story streams differed from each other.

Data Structure, Management, and Variable Creation

WKe-Book user-logs were generated automatically every time students logged into their account. User-logs included data on every page viewed, including the specific button pressed, which story streams each student was reading, their response to each question, and the amount of time spent on each page. For example, students could go back, forward, answer the multiple-choice questions, and make decisions about what their characters would do next in the story.

An event was recorded every time a student logged in and clicked on a page. The total number of events logged was 227,129. Each event was tagged by the student's ID, allowing us to examine each student's unique behavior. Based on the data contained in the user-logs, we theorized that behavior on text-only pages, question pages, and story stream decision pages where the student had to choose an appropriate path, would relate to reading outcomes. The raw user-logs contained an abundance of information that had to be significantly modified before being analyzed. Therefore, using the Python programming language (version 2.7), we extracted

and manipulated the data from the raw user-logs to create the desired study variables and an analysis dataset (see Figure 1).

Time on text-only pages. To create a variable for reading time on text-only pages, we calculated the average time that a student spent on all the text-only pages they accessed in the book. We truncated the maximum reading time on a single text page to 10 minutes, as such a long time on a page was likely due to being logged in but involved in non-reading behaviors (e.g., using the restroom, forgetting to log out).

Time on question pages. To create a variable for time on question pages, we calculated the average time that a student spent on all the question pages they accessed in the book. We truncated the maximum time spent on a single question page to a maximum of 10 minutes.

Questions correct. To create a variable for the embedded questions answered correctly, we calculated the percentage of questions answered correctly per student for every question accessed. Every question was formatted as a multiple-choice question with four choices. This variable includes questions that students encountered and answered multiple times.

Story stream decisions (SSD). To create a variable for understanding behavior on story stream pages with only one plausible option, we created a variable for the total number of implausible choices a student made. Story stream decisions were of two types; one type allowed students to select between two plausible options of what the characters might do. This type of story stream decision was not analyzed as it was a motivational feature and not an assessment feature. The second type of story stream decision presented the reader with two options of what action the characters should take. Only one action was reasonable and plausible for the story. The other option was implausible and led to a dead-end in the story. If the student made an implausible decision and reached a dead-end, he/she was sent back several pages to reread and

make a better decision. The variable created was heavily right skewed, so the variable was made dichotomous. If a student selected more than two implausible choices, the variable *story stream decisions* was coded as one to reflect a high frequency of poor decision-making. Seventy-seven percent of students made two or less implausible story stream decisions, for whom this variable was coded as zero.

Assessment Measures

Word Knowledge Task. This task was designed to assess knowledge of the target vocabulary words in the WKe-Book. However, not all students were exposed to the exact same targets words due to the possibility of selecting different story streams. The task was divided into three subsections: *Matching, What's the Meaning of This,* and *Let's Figure It Out*. In the *Matching* subtest, students had to match vocabulary words with the correct definition from three choices. In the *What's the Meaning of This?* subtest, students had to read a sentence that included a target word and choose a synonym from a bank of three words. In the *Let's Figure It Out* subtest, students had to read a sentence and write the definition of the underlined target word. The Word Knowledge Task was administered at the beginning of the study, at the mid-point, and at the end of the study (overall alpha reliability = 0.892). In this study, we only used the pre and post scores.

Word Knowledge Confidence. This task assessed students' word knowledge confidence and perceived calibration. The task included 7 items, and students were given target words and asked to circle whether or not they knew what each word meant. Then, they were asked to define the word. Similar to self-efficacy, we conceptualize word knowledge confidence as a student's self-assessment of their word knowledge, which may or may not be accurate. For example, students overestimated their word knowledge (i.e., said they knew the word but could not define

it) 11% of the time. Overall, reliability on the entire measure was acceptable with alpha of 0.805. We used this measure as a proxy for reading self-efficacy.

Reading Comprehension. The Gates-MacGinitie Reading Test assessed students' reading comprehension at the mid-point of the study. In the comprehension subtest, students read paragraphs and had to select the correct answer demonstrating literal and inferential comprehension. For the analyses, we used the extended scale scores (ESS) with a mean of 500 and a standard deviation of 15. The published reliability for this test is 0.960.

Analysis plan

After creating the necessary variables from the user-logs, descriptive statistics were used to understand how students engaged with the WKe-Book (RQ1). To answer our second research question, correlations between reading comprehension on the Gates-MacGinitie and WKe-Book behaviors were investigated. To answer our third and fourth research questions about the relations between word knowledge confidence, WKe-Book behaviors, and word knowledge gains, structural equation modeling (SEM) was employed. Our model included two main WKe-Book reading behaviors, time on text-only pages and time on question pages, as predictors of answering embedded questions pages correctly and frequency of making implausible choices in story stream decisions (see Figure 2 for our hypothesized model). These two WKe-Book outcomes were conceptualized to mediate the relationship between time on text-only and question pages and gains in word knowledge. Grade level (fourth grade coded as the reference group), pretest word knowledge, and word knowledge confidence were included as predictors. Finally, book club participation was entered as a predictor of WKe-Book outcomes and word knowledge gains.

Stata 15 was used to estimate the complete path model, and full information maximum likelihood was used to account for missing data. Model fit for all models was first assessed using the chi-squared statistic (χ^2), as it is the only inferential statistic in SEM for model fit. Additionally, we used two alternative fit indices, the root mean error of approximation (RMSEA) and the comparative fit index (CFI). RMSEA values below .08 and CFI values greater than .95 indicated good fit (Acock, 2013; Little, 2013).

Results

There were several important descriptive findings that answered our first and second research questions about students' WKe-Book interactions and how these are related to scores on the Word Knowledge task and reading comprehension test. Descriptive statistics are reported in Table 1 and correlations are reported in Table 2. Over the entire sample, the average time on text-only pages was 44 seconds with a standard deviation of 23 seconds. Mean reading time on text pages for students in the lowest and highest quartile of the word knowledge posttest was the exact same, 41.7 seconds. Over the entire sample, the average time on question pages was approximately 15 seconds. Students answered questions correctly 59% of the time. Students whose scores were in the lowest quartile on the word knowledge posttest spent significantly less time on question pages (mean of 13.5 seconds) than the other three quartiles (t=2.72, p<.01). Scores in lowest quartile on the posttest answered only 50% of the questions correctly, whereas students whose scores were in the highest quartile answered questions correctly 70% of the time. Students story stream decision behavior (i.e., making implausible decisions) showed significant variation. Fifty-nine percent of students made one or no implausible story stream decisions, 18% chose two implausible story stream, and 23% chose three to fourteen implausible story stream decisions (in this instance, children fell into the same trap multiple times). Students' time on

text-only pages significantly varied between those who made frequent implausible story stream decisions versus those who did not (t=8.49, p<.001). Those who made more than two implausible story stream decisions read text-only pages for 30.13 seconds on average, whereas those who made two or fewer implausible SSD averaged 48.22 seconds.

We found that reading comprehension (see Table 2), as measured by the Gates-MacGinitie, was positively correlated with answering questions correctly, spending less time reading text-only pages, and word knowledge confidence; whereas it was not correlated with time spent reading question pages or making implausible story stream decisions. Overall, students with stronger reading comprehension had stronger word knowledge pre- and posttest scores. Third graders had weaker reading comprehension skills than did fourth graders, and fifth graders tended to have the strongest reading comprehension scores of all, as expected since we were using ESS scores, which capture growth in scores.

Student characteristics and WKe-Book behaviors predicting word knowledge gains.

We used SEM to answer our third and fourth research questions. Our model had excellent fit and replicated the covariance matrix (χ^2=7.45(6), p=.28; RMSEA=.02; CFI=.99). The path diagram with standardized coefficients is provided in Figure 3 (also see Table 3). There were two direct effects on word knowledge posttest scores: students who were randomly assigned to book club and those who had stronger word knowledge pretest scores generally had higher scores on the word knowledge posttest. Students who answered a higher percentage of questions correctly while they were reading the WKe-Book also generally had better posttest scores. Additionally, the percentage of questions answered correctly mediated the effect of three student reading characteristics on posttest scores: students with higher pretest scores, those with greater word knowledge confidence, and those who spent more time on questions pages generally answered a

higher percentage of questions correctly, which, in turn, predicted higher posttest scores. Third graders (compared to fourth and fifth graders) were less likely to answer questions correctly while reading the WKe-Book and generally achieved lower posttest scores. Finally, fifth graders (compared to third and fourth graders) and students who spent more time on text-only pages were less likely to make implausible story stream decisions. However, making implausible story stream decisions was not associated with word knowledge test score gains.

Our fourth research question pertained to the effects of book club participation on WKe-Book outcomes and word knowledge gains. Returning to the SEM analyses (Figure 3 and Table 3), participation in the book club was associated with making fewer implausible story stream decisions, but contrary to our hypothesis, was not associated with answering embedded questions correctly (p=0.68). Overall, students who participated in book clubs made greater gains in their word knowledge.

Discussion

The present study utilized user-logs of third to fifth graders who read an interactive WKe-Book to investigate the associations between reading behaviors and gains in word knowledge. One of our principal aims was to examine whether the user-logs might provide insights into students' reading strategies and behaviors while they were reading, including prospective decision-making (Chernyak et al., 2017). Our hypotheses were supported but not completely, with implications for both theory and practice.

Students' Reading Behaviors and Word Knowledge

User-logs were useful in understanding how reading behaviors varied systematically by students' background and reading characteristics, including having higher pretest scores, greater word knowledge confidence, and those who spent more time on question pages, which directly

and indirectly affected their word learning. Overall, we found that students varied substantially in the amount of time they spent on text-only pages and question pages. Interestingly, we found that students with both the strongest and weakest word knowledge skills read text-only pages at the same rapid pace compared to those with more average word knowledge skills. Generally, greater fluency (faster reading) is associated with stronger reading comprehension (Kim, Petscher, Schatschneider, & Foorman, 2010; Klauda & Guthrie, 2008), so this result suggests a Goldilocks effect. We assumed that students with stronger word knowledge were likely able to read quickly because they were comprehending the text well; whereas readers with weaker word knowledge were likely not comprehending the text as easily and as a result, we conjecture, they read the text quickly and carelessly. It may be the case that readers with weaker word knowledge were not aware that their standards of coherence were not met and thus, they kept reading without monitoring their comprehension. This non-linear relation might explain why the time students spent reading text-only pages did not predict their posttest word knowledge scores; yet when they spent more time reading text-only pages they were less likely to make implausible story stream decisions. A similar phenomenon was reported by Connor and colleagues (2015) where fifth graders with weaker semantic skills spent less time re-reading implausible sentences, compared to their peers with stronger semantic skills and thus had faster reading times.

Further supporting the fluency and strategic reading conjectures, the students in the *lowest* quartile on the word knowledge posttest spent significantly less time on question pages than other students and answered these questions correctly less often. Upon closer inspection of the user-logs, cases were identified where students quickly read a question, answered incorrectly, guessed again within seconds, and repeated this process until they answered correctly. It appears that these students were not utilizing reading strategies consistently and were gaming the system

by rapidly clicking through the multiple-choice options to employ a guess-and-check approach in order to move on. In contrast, students in the higher quartiles spent significantly more time on question pages and were more likely to answer the questions correctly the first time. While it may be that weaker readers were simply not motivated to answer the questions more carefully, these findings also suggest that students with weaker word knowledge may be less able to judge whether their standards of coherence are met. Additionally, they might not have the skills in their toolbox to employ effective strategies to aid their comprehension of difficult words and text. Conversely, students in the highest quartile of word knowledge were generally able to automatically speed up their reading on text pages and strategically slow down on question pages in line with their standards of coherence. This confirms findings by Salmerón and colleagues (2015) who suggested that more able readers likely approach task-oriented reading assignments strategically by reading text carefully before answering questions. Strategic reading allows for constructing coherent representations of the text to be used in correctly answering questions.

Implausible Story Stream Decisions

The WKe-Book allowed students to choose-your-own-adventure by making story stream decisions. We examined story stream decisions where one choice was clearly not plausible, called implausible story stream decisions. This allowed us to examine more carefully what decisions students made based on their standards of coherence (e.g., use of strategic cognitive processes) and whether they continued to make the same poor decisions. Making a good decision required students to comprehend the text, including the two target words, as well as to engage in prospective decision-making (Chernyak et al., 2017), which is a metacognitive task (e.g., if I make this decision, what will happen?). Overall, students generally avoided making implausible story stream decisions. Because the consequence of making an implausible decision was to be

sent backwards in the story, most students appeared to be cautious and attentive on these decision pages to avoid being sent back. Some students made the same implausible decision multiple times, likely reflecting a lack of focus on these pages. Surprisingly, implausible story stream decision-making was not associated with reading comprehension skills. It is possible that students purposely clicked on the implausible option out of curiosity, wondering what might happen. Still, these students were more likely to be in the no-book-club condition, and to spend less time reading question and text-only pages. Thus, indirectly, students who made implausible decisions were generally less likely to make gains in word knowledge. Word knowledge confidence was not related to making implausible decisions, so we do not have evidence that implausible decision-making was related to poor reading self-efficacy.

Differences by grade

Third graders performed significantly worse than fourth and fifth graders on the word knowledge posttest, answering embedded questions; and they made implausible story stream decisions more frequently. Fifth graders did not perform significantly different than fourth graders; however, they did make fewer implausible story stream decisions. This finding was not that surprising considering third grade students, in general, have weaker reading skills compared to fifth grade students. It may also have been the case that the target words were too complex for them to comprehend or that learning the reading strategies were more difficult for them to implement. This further supports the metacognitive aspect of prospective decision-making, since metacognitive skills are just beginning to be established in third grade and improve through adolescence (Del Giudice, 2014; Kolic-Vehovec, Bajsanski, & Zubkovic, 2010).

Relations between reading comprehension and reading behaviors

We were interested in understanding how reading comprehension related to students' WKe-Book reading behaviors. As anticipated, students with stronger reading comprehension exhibited behaviors while reading the WKe-Book that were associated with greater word knowledge gains. They generally answered more questions correctly, spent less time reading text, and had greater word knowledge confidence. They also had higher pretest scores on our Word Knowledge task. However, there were behaviors associated with higher performance on the Word Knowledge task that were not associated with students' reading comprehension, including: time spent reading question pages, avoiding implausible story stream decisions, and attending the book club (which was randomly assigned). Thus, there appear to be other aspects of reading, such as metacognition, that contributed to gains in word knowledge.

Relations between reading behaviors, word knowledge gains, and book club participation

We also investigated the relations between WKe-Book reading behaviors and word knowledge, in addition to the effect that scaffolding via a book club had on students' reading behaviors and word knowledge. Although time spent on question pages was not directly related to posttest word knowledge, it was a strong predictor of answering embedded questions correctly. Students who spent more time on question pages answered them correctly more often, and answering questions correctly explained (i.e., mediated) the effect of time on question pages on the posttest word knowledge task. Students who spent more time reading the questions may have been more motivated to choose the correct answer and generally demonstrated greater word knowledge gains. These findings align with research demonstrating that making more thoughtful decisions while reading is associated with stronger reading comprehension (Salmerón & García, 2011; Naumann, 2015).

The embedded questions in the WKe-Book were designed to encourage strategic reading, which are processes that readers need to employ when their standards of coherence are not met (van den Broek et al., 2005). Students were prompted to use context clues, word history, or the dictionary to determine the correct answer. If they chose the incorrect answer, they were provided with feedback encouraging them to utilize these strategies to repair their understanding. Surprisingly, although book club participants performed better on the word knowledge posttest and made less implausible story stream decisions, book club participation was not associated with answering embedded questions correctly. This may be partially because students in the book club condition only met with the research teacher three times during the three-week period of WKe-Book reading. More frequent group discussion may be more effective than what was allotted in this study. Additionally, some students may have had difficulty transferring the strategies they learned in the book club to their actual reading of the WKe-Book. It may be effective, in future versions of the WKe-Book, to encourage students more explicitly to employ reading strategies while reading. For example, pop-ups providing hints on which strategy may be most effective may be helpful for students instead of just providing feedback after they choose a response. These findings align with previous work from McMaster and colleagues (2015) that examined differences in fourth grade students who read both online and offline texts and answered comprehension questions. Their findings demonstrated that when reading online texts, immediate prompting was particularly useful in helping students make meaningful connections between difficult sentences in text compared to subsequent questioning in small groups. They also theorized that comprehension difficulties may often be due to lack of awareness that they need to make a connection rather than an inability to make connections. In other words, students may not always be aware that their standards of coherence are not met. Thus, providing more

immediate prompts and encouraging students to monitor their comprehension when reading difficult text should be an important consideration in future work.

Limitations

There are a few limitations to note in this study. First, although using the dictionary was a targeted strategy and students had access to the iPad dictionary, the logs could not capture dictionary usage, so we were not able to assess what effect dictionary use may have had. The WKe-Book is accessed via a web browser and forced us to use the Apple dictionary which is a functionality of the iPad itself. Thus using the dictionary could not be detected. Additionally, our participants attended schools where a high proportion of the students were from lower income families. On average, students in this sample were reading at about the 30th percentile. Plus, a high proportion of the students were dual language learners. Unfortunately, Arizona school policy precluded assessing students in Spanish. Thus, these findings may not generalize to other schools and populations.

Future Directions

In this study, we relied exclusively on user-logs to understand reading behavior. However, process data could not inform what students were exactly thinking while on each reading page, question, or decision page. In order to better measure their actual standards of coherence, future research should consider adding embedded survey questions that directly measure students attitudes, beliefs, strategy use, and other individual characteristics of the reader that would relate to the implicit and explicit criteria employed. Furthermore, future studies should focus on adding features that will optimize student engagement and learning. Considering the Universal Design for Learning theory (Rose, 2000), if a learner is having difficulty learning a certain concept, it may be due to the design of the technology rather than the fault of the learner.

For example, regarding the story stream decisions in the WKe-Book, when a student repeatedly made implausible decisions, current results demonstrated that simply requiring the student to re-read the chapter was not an effective way to teach him/her to employ the targeted reading strategies. In most cases, these students just clicked to the next page very rapidly, so they could get back to the question page again to select a different answer without, apparently, re-reading the story. Students who repeatedly make poor decisions or who continue answering a comprehension question incorrectly may require more individualized feedback. Thus, future work is underway to examine whether providing more tailored feedback and different kinds of questions will improve student learning. If a student repeatedly answers a question incorrectly, they may benefit from pop-ups that provide extra hints about which strategies they could use to decipher the meaning of a target word.

Conclusions

Overall, the results of this study begin to demonstrate how user-logs can be utilized to better understand students' reading behavior in elementary school. User-logs can be used as an assessment to identify students who are not reading strategically and to explicate the role of metacognition, such as prospective decision-making, which is not possible in post hoc assessments. Additionally, these results also show that interactive e-books may be a useful tool for teaching students effective reading strategies to repair their misunderstanding of challenging text.

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Table 1

Means, standard deviations, minimum, and maximum for all variables

	Mean	SD	Min	Max
Gates-MacGinitie Comprehension				
Extended Scale Score (ESS)	463.16	32.46	364	595
Word knowledge confidence	2.41	1.69	0	7
Percent correct of embedded questions	0.59	0.14	0	1
Average time on question pages	15.19	9.00	1	60
Average time on text-only pages	44.08	22.87	2	148
Word Knowledge Pretest Total	20.79	8.89	2	56
Word Knowledge Posttest Total	27.40	11.79	2	60
Implausible story stream decisions	1.58	1.72	0	14
Book club Participation	0.49	0.50	0	1
N	581			

Table 2

Correlations

	%Questions Correct	Question Time	Text Time	WK Pretest	WK Posttest	SSD	Book club	WK Confidence	GMRT	3rd Grade	5th Grade
% Questions correct	1.00										
Question Time	0.29***	1.00									
Text Time	0.05	0.47***	1.00								
WK Pretest	0.49***	0.09*	-0.08	1.00							
WK Posttest	0.49***	0.08	-0.03	0.72***	1.00						
SSD	-0.04	-0.23***	-0.33***	-0.05	-0.06	1.00					
Book club	0.00	0.07	0.01	0.03	0.07	-0.10*	1.00				
WK Confidence	0.25***	0.02	-0.11*	0.28***	0.27***	0.03	-0.04	1.00			
GMRT	0.50***	0.03	-0.13**	0.70***	0.73***	-0.02	-0.04	0.32***	1.00		
3rd Grade	-0.37***	-0.12**	-0.03	-0.44***	-0.44***	0.07	0.03	-0.28***	-0.43***	1.00	
Fifth Grade	0.39***	0.20***	0.07	0.50***	0.44***	-0.12**	-0.04	0.29***	0.42***	-0.52***	1.00

Note. WK = word knowledge; GMRT = Gates MacGinitie Reading Test
SSD = implausible story stream decisions
* p<0.05, ** p<0.01, *** p<0.001

Table 3

SEM of WKe-book behaviors predicting reading outcomes

	Beta	SE	Z	p-value
WK Posttest				
% Questions Correct	0.16	0.03	4.78	0.00
SSD	-0.01	0.03	-0.41	0.68
Pretest WK	0.57	0.03	18.45	0.00
3rd Grade	-0.10	0.03	-3.07	0.00
5th Grade	0.04	0.04	1.17	0.24
Book club	0.06	0.03	2.02	0.04
% Questions Correct				
WK Pretest	0.35	0.04	8.93	0.00
3rd Grade	-0.12	0.04	-2.85	0.00
5th Grade	0.08	0.04	1.86	0.06
Book club	-0.01	0.03	-0.41	0.68
WK Confidence	0.09	0.04	2.52	0.01
Question Time	0.25	0.04	6.47	0.00
Text Time	-0.04	0.04	-0.91	0.36
SSD				
3rd Grade	0.01	0.05	0.23	0.82
5th Grade	-0.09	0.05	-1.98	0.05
Book club	-0.10	0.04	-2.49	0.01
Question Time	-0.06	0.04	-1.35	0.18
Text Time	-0.30	0.04	-7.30	0.00
Variance				
WK Posttest	0.45	0.02		
% Questions Correct	0.66	0.03		
SSD	0.86	0.03		

Note: All results are standardized. SE = Standard error.

$\chi 2 = 7.45$ df(6), p=.28; RMSEA = .02; CFI = .99

Event_ID	Timestamp_ Date	Timestamp_ time	Time_On_Page	Type_Name	Button_ Name	Item_ID	Response	Correct	Page_Name
255687	2015-01-12	17:08:51.963		testStarted					dl_title.html
255906	2015-01-12	17:10:49.727	00:01:57.763	buttonPressed	Next				dl_title.html
255919	2015-01-12	17:10:56.537	00:00:06.283	buttonPressed	Prev				dl_introduction.html
255920	2015-01-12	17:10:56.827		testStarted					dl_title.html
255931	2015-01-12	17:11:03.250	00:00:06.423	buttonPressed	Next				dl_title.html
256347	2015-01-12	17:14:09.660	00:03:06.130	buttonPressed	Next				dl_introduction.html
256474	2015-01-12	17:15:12.763	00:01:02.533	buttonPressed	Prev				dl_selectnames.html
256581	2015-01-12	17:15:53.833	00:00:40.660	buttonPressed	Next				dl_introduction.html
256718	2015-01-12	17:16:54.613		textEntered					dl_selectnames.html
256719	2015-01-12	17:16:54.967		textEntered					dl_selectnames.html
256721	2015-01-12	17:16:55.160	00:01:01.000	buttonPressed	Next				dl_selectnames.html
256856	2015-01-12	17:17:51.447	00:00:55.887	buttonPressed	Next				dl_instructions.html
257043	2015-01-12	17:19:19.133	00:01:27.257	buttonPressed	Next				dl_c1_p01.html
257147	2015-01-12	17:20:14.120	00:00:54.290	buttonPressed	Next				dl_c1_p02.html
257263	2015-01-12	17:21:37.583	00:01:23.077	buttonPressed	Next				dl_c1_p03.html
257319	2015-01-12	17:22:44.550	00:01:06.533	buttonPressed	Next				dl_c1_p04.html
257329	2015-01-12	17:22:58.283	00:00:13.327	itemResponse		100	3	0	dl_c1_p05_q.html
257331	2015-01-12	17:22:58.747	00:00:04.547	pageLoad					dl_c1_p05_fb_d.html
257352	2015-01-12	17:23:22.147	00:00:18.853	buttonPressed	Next				dl_c1_p05_fb_bd.html
257372	2015-01-12	17:23:32.477	00:00:10.010	itemResponse		100	2	1	dl_c1_p05_q.html
257373	2015-01-12	17:23:32.893	00:00:04.427	pageLoad					dl_c1_p05_fb_c.html

Figure 1a. Raw user-log sample in long format of a student going from the title page (dl_title.html), to reading page one of chapter one (dl_c1_p01.html) for one minute and 27 seconds, to reading a question page (dl_c1_p05_q.html) for 13 seconds.

Child ID	% Correct	Time_question	Attempts To correct	time_to_correct	Text time	Total SSD
440	0.45	15.73	2.95	90.81	74.44	1
441	0.35	4.53	5.68	40.44	67.16	1
464	0.62	19.53	2.64	56.83	77.12	0
465	0.66	14.13	2.89	54.73	57.84	1
442	0.46	10.79	3.02	138.95	26.93	5
466	0.49	19.07	2.87	63.33	56.86	3
171	0.46	15.70	2.91	99.51	68.56	0
467	0.63	10.98	2.65	34.09	44.41	3
468	0.66	13.92	2.59	374.05	54.53	1
443	0.69	23.75	2.43	64.71	44.36	1
469	0.63	9.19	3.72	72.03	47.94	4
444	0.33	8.42	3.27	179.89	58.27	3
471	0.68	7.92	2.55	155.02	34.31	2
754	0.39	15.50	3.06	104.65	82.73	1
445	0.70	15.84	2.44	200.15	56.40	2
472	0.40	5.52	3.03	29.32	40.56	6
172	0.45	15.60	2.44	45.80	72.55	0
473	0.46	9.82	3.00	60.77	49.08	0

Figure 1b. Adapted user-log data in wide format showing WK-ebook variables generated including time on question and text pages, percentage of questions answered correctly, and total implausible SSD made.

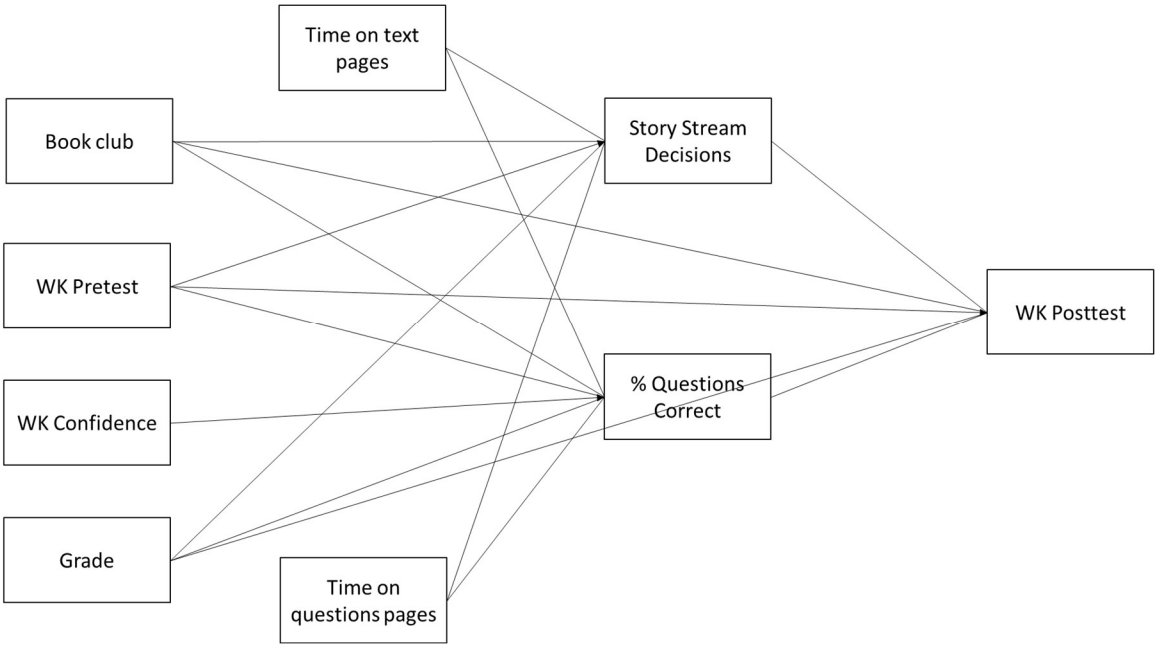

Figure 2. Proposed SEM of associations between study variables and students' posttest word knowledge scores. *Note*. WK represents Word Knowledge task.

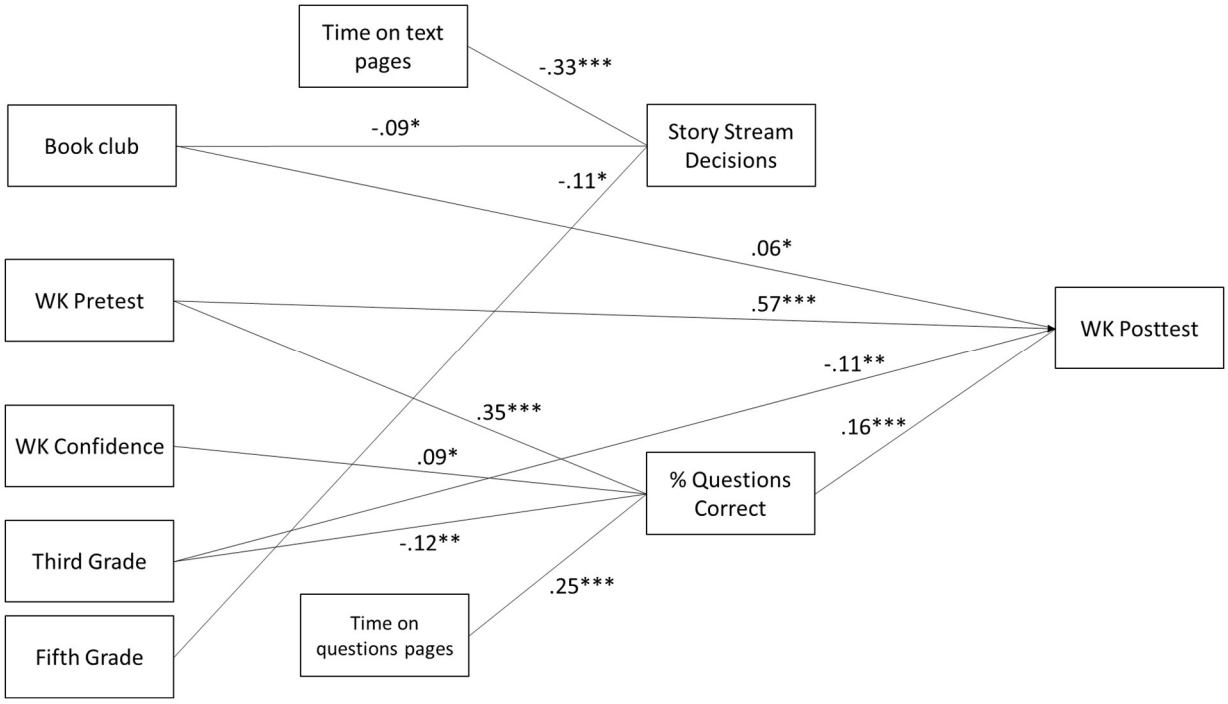

Figure 3. Final SEM results showing standardized coefficients of associations between WKe-Book variables, book club intervention, word knowledge confidence, and students' posttest word knowledge scores. Only significant paths shown.

Appendix

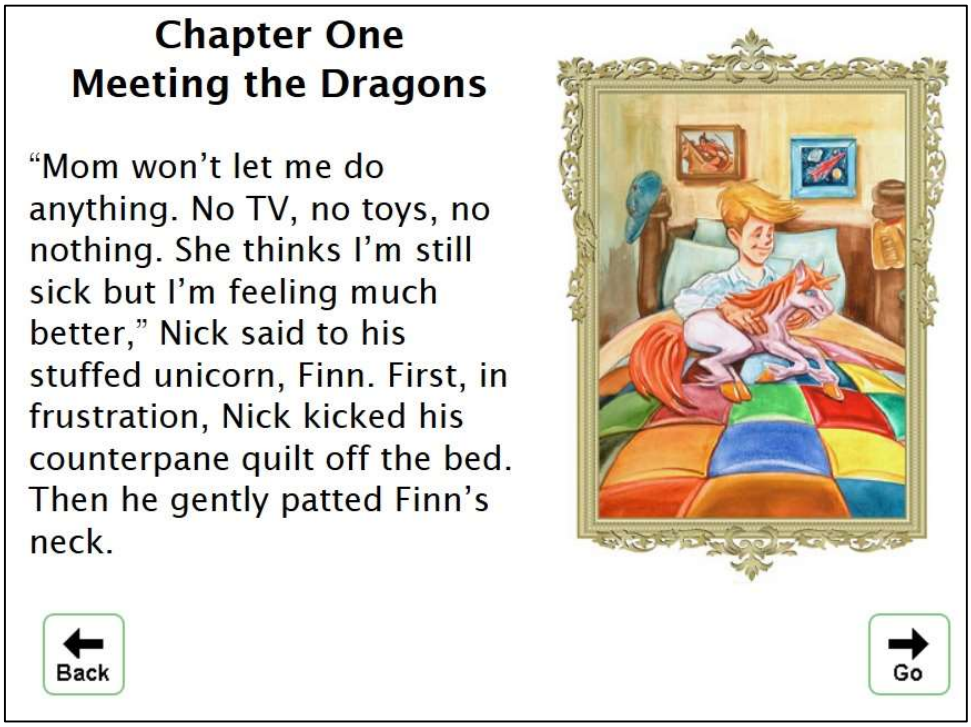

Figure 1. Example of a text-only page

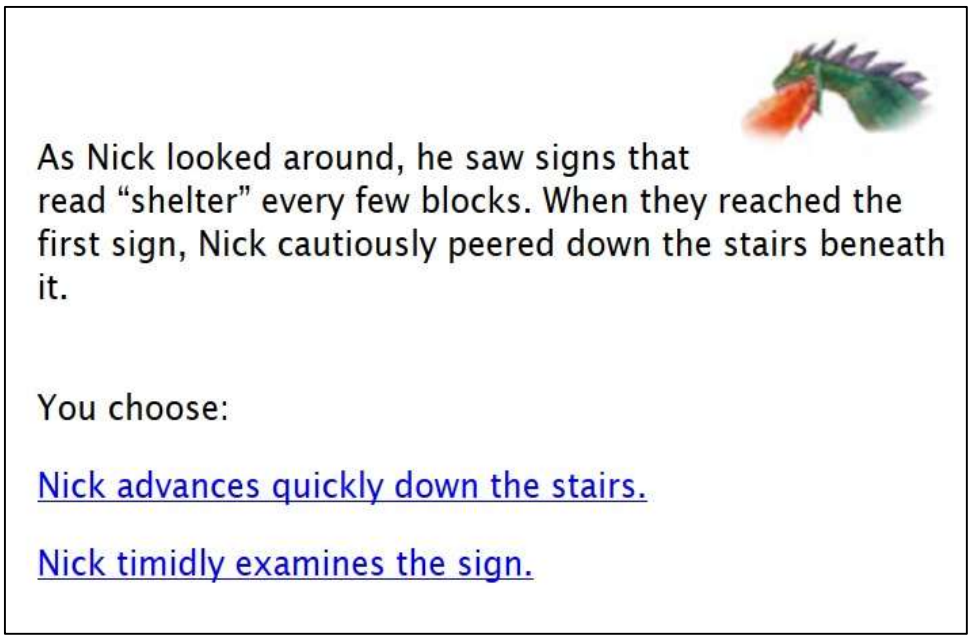

Figure 2. Example of a story stream decision page

What does it mean that Lakeisha interrupted Ralphy?

She is reassuring him.
She is impatient with him.
She doesn't want him to worry.
She didn't let him finish what he was saying.

You are not quite right.

Lakeisha might have interrupted Ralphy because she was impatient. But that is not what interrupt means. When you interrupt somebody, you stop them abruptly and don't let them finish what they are trying to say.

Did you notice the three dots, "…"? The three dots mean that something is incomplete. What do you think Ralphy is trying to say?

Read the page again, now that you know what "interrupt" means.

Figure 3. Example of a question page (top) and the feedback provided after the reader responds incorrectly (bottom).