Received: 16 September 2018 | Revised: 1 August 2019 | Accepted: 22 August 2019

DOI: 10.1002/dys.1634

RESEARCH ARTICLE

WILEY

Supplementing teacher knowledge using web-based Intelligent Tutoring System for the Text Structure Strategy to improve content area reading comprehension with fourth- and fifth-grade struggling readers

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The effects of teaching the text structure strategy using a web-based Intelligent Tutoring System for the Text Structure Strategy (ITSS) were examined with fourth- and fifth-grade children scoring below the 25th percentile on comprehension measures using the Gray Silent Reading Test (GSRT) and researcher designed assessment from 130 fourth-grade and 130 fifth-grade classrooms. The ITSS was designed to teach students how to select and encode strategic memory from expository texts. The system provides modelling, practice, assessment, scaffolding, and feedback to learners on identifying signalling words, summarizing, making inferences, generating elaborations, and monitoring comprehension. A large scale randomized controlled trial was conducted with 130 fourth-grade and 130 fifth-grade classrooms. Students completed GSRT- and researcher-designed measures of reading comprehension at pretest and posttests. An analysis of fourth-grade students using ITSS who scores less than the 25th percentile on the GSRT pretest showed small but meaningful effect sized on the posttests. The fifth-grade students in ITSS, who scored less than the 25% percentile on the GSRT pretest, showed the highest effect sizes (moderate to large effects) on the standardized test scores on the posttests.

KEYWORDS
elementary grade, reading comprehension, struggling reader, teacher quality, web-based tutoring

1 | INTRODUCTION

A child who fails to read proficiently at fourth grade will most likely remain a poor reader throughout school with persistent lifelong struggles (Fletcher, Coulter, Reschly, & Vaughn, 2004) as she/he faces continuing challenges in comprehending advanced content area texts. Unfortunately, teacher knowledge and practices associated with reading comprehension appear to be a challenge at upper elementary grade levels (Beerwinkle, Wijekumar, Walpole, & Aguis, 2018; Pressley, Wharton-McDonald, Mistretta-Hampston, & Echevarria, 1998). Both student outcome and teacher knowledge trends cannot continue, and solutions must be developed to address these problems as early as possible. In fourth grade, children begin the reading to learn phase, and in fifth grade, they are expected to display stronger comprehension skills so that they can be prepared for middle school level rigour in the content areas (Chall, 1983). Thus, children who experience difficulties in reading and comprehending expository texts at both fourth and fifth grades will continue to face serious consequences throughout life. Being poor magnifies the problem as children growing up in low-SES communities are most likely (74%) to score at the lowest 25th percentile on the National Assessment of Educational Progress (2015). According to Marshall (2013), "Two-thirds of students who cannot read proficiently by the end of the 4th grade will end up in jail or on welfare" (p. 27). Teaching all children to read and comprehend effectively is an important goal for their academic and professional success as well as the vitality of our society. The purpose of this research was to study the efficacy of a web-based Intelligent Tutoring System for the Text Structure Strategy (ITSS) designed to deliver one on one intervention about the text structure strategy to fourth- and fifth-grade readers who scored at the lowest 25% percent on a standardized reading comprehension test and are referred to as struggling readers in this manuscript.

2 | BACKGROUND

Reading comprehension is a complex skill that is developed through many years of iterative knowledge and skill acquisition, application, and transfer. Components of the reading comprehension journey include grapheme–phoneme awareness, word knowledge, vocabulary, background and contextual knowledge, knowledge about text genres, fluency in reading, comprehension strategy knowledge, metacognitive, and motivational skills. A child who is experiencing difficulties in successfully reading and comprehending content area texts may be lacking any one or more of the component skills and/or have some disabilities to overcome (Guthrie et al., 2009; Lovett, Lacerenza, & Borden, 2000).

Solutions to the problems facing struggling readers displaying persistent reading difficulties have focused primarily on early elementary grades (Blachman et al., 2004; Denton, Fletcher, Anthony, & Francis, 2006; Felton, 1993; Fletcher, Lyon, Fuchs, & Barnes, 2007; Jenkins & O'Connor, 2002; Mason, 2004; Mathes et al., 2005; McMaster, Fuchs, Fuchs, & Compton, 2005; Torgesen et al., 1999) and middle and upper school levels (Edmonds et al., 2009; Kamil et al., 2008; Scammacca et al., 2007; Torgesen et al., 2007). Kamil et al. (2008) suggested that fourth and fifth graders are more similar in comprehension needs to middle-grade children than primary school children. Even though the constructs being taught may be the same (e.g., word meaning), the interventions and reading content must be appropriate for children at fourth or fifth grade. Interventions designed for middle school concentrate on moving children into reading texts appropriate for those grade levels and thus may not be easily adapted to fourth- or fifth-grade children. Additionally, it is important to provide interventions to children as early as possible in Grades 4 and 5 to

avoid recurring and continuing academic and self-efficacy related challenges. Thus, our first goal was to develop and present an intervention suitable for fourth- and fifth-grade children with materials appropriate for the grade levels.

A second area of concern for developing interventions for struggling readers is the need for consistent high-quality instruction that may be easily adapted to the learning context as a Tier 1, 2, or 3 implementation. Fletcher et al. (2004) Response to Intervention (RTI) promotes customized instruction at whole group, small group, or individual levels based on student mastery of learning. Yet research has also shown that most teachers do not have the skills or are unable to provide consistent high-quality instruction in their classrooms on reading comprehension (Pressley et al., 1998) and decoding (Binks-Cantrell, Washburn, Joshi, & Hougan, 2012; Joshi et al., 2009) to all their students, especially those with reading difficulties (Klingner, Urbach, Golos, Brownell, & Menon, 2010; Levy & Vaughn, 2002; Swanson & Vaughn, 2010). This phenomena was aptly described as the Peter effect where teachers cannot teach what they do not know themselves (Binks-Cantrell et al., 2012). Advances in intelligent tutoring technologies may provide a better solution to overcome challenges related to developmental variations and pathways of children as well as teacher/instructional limitations by providing prescriptions for targeted instruction.

Finally, struggling readers may lack skills related to fluency, vocabulary knowledge, and reading comprehension strategy for expository texts at fourth and fifth grades. Wanzek et al. (2017) present positive results from a recent study on a multi component intervention called Passport to Literacy with fourth-grade students. In this intervention, students received structured year-long instruction about phonics, word recognition, conceptual and background knowledge, and comprehension monitoring, and the effect size on reading comprehension outcome with the bottom 30% percentile of students was 0.38. Wanzek et al., described the intervention surrounding comprehension as "explicit instruction in previewing, setting purpose, text structure and evaluation, making inferences and taking perspectives, drawing conclusions, author's purpose, sequencing, main idea, summarizing, independent reading fix-up strategies, teacher and reader questioning, and making connections within and across texts" (p. 5). Based on the description presented, we may note that text structures are presented as one of many strategies and as if they are independent from summarizing, sequencing, and so on. This pattern is observed in other upper elementary grade interventions (e.g., Vaughn, 2015). Connor et al. (2011) and Therrien, Wickstrom, and Jones (2006) have used strategies that have produced positive effects on vocabulary, fluency, and other foundational skills.

The text structure strategy developed by Meyer and Wijekumar (2007) and Meyer, Young, and Bartlett (1989) presents five text structures integrated with summarizing and other comprehension-promoting activities and thus provides an alternative application of text structures that may scaffold comprehension with struggling readers. This interpretation of text structure-based reading comprehension instruction has yielded positive results with first- and second-grade struggling readers (Williams et al., 2016; Williams, Hall, & Lauer, 2004). The close analysis of texts with structure intervention developed by Williams focuses on teaching all five text structures, integrates summarizing and inferences with text structures, and has shown strong results with second-grade struggling readers. Results show that students learning text structures outperformed control group students and performed well on content knowledge tests as well. However, close analysis of texts with structure has not been extended to upper grade levels.

The focus of our research was to address the unique demands of fourth- and fifth-grade students transitioning from learning to read to the reading to learn stage of reading comprehension. We also focus on classrooms where struggling readers may lack high-quality and consistent instruction that can be made universally available through technologies. Our solution is a web-based ITSS for the structure strategy that teaches children in Grades 4 and 5 how to read and comprehend content area texts using the structure strategy.

3 | THEORETICAL AND EMPIRICAL SUPPORT FOR THE STRUCTURE STRATEGY AND ITSS

The structure strategy is a text structure-based instructional approach for improving content area reading comprehension with theoretical and empirical supports (Meyer, 1975; Meyer et al., 2010; Wijekumar et al., 2014;

Wijekumar, Meyer, & Lei, 2012). The approach teaches children how to select important ideas from the text and make logical associations (e.g., find the cause–problem–solution) between the ideas, integrating them with prior knowledge. The connections between the ideas are made through the five text structures identified by Meyer (1975)—comparisons, problems and solutions, causes and effects, sequences, and descriptions.

This intervention differs from existing practice in that it focuses on (a) text structure strategy framed instruction to improve content area reading comprehension (e.g., write a main idea using the comparison pattern); (b) consistent and high-quality intervention using web-based technologies to extend instruction (overcoming any teacher knowledge deficITSS or teacher time limitations); and (c) computer- and teacher-supported instruction on vocabulary knowledge (e.g., preview of vocabulary in lessons), attentional control (e.g., modelling of how to locate important ideas), and/or self-regulation (e.g., monitor comprehension), for the individual cognitive and metacognitive needs of struggling readers in Grades 4 and 5.

In this implementation, all five text structures are presented with reading passages from multiple domains (e.g., science, social studies, and sports). Many real-life texts use nested text structures to showcase interrelationships among the ideas in the text. Therefore, the ITSS presents nested structures to the students within lessons. For example, an article about the explosion in the Gulf of Mexico may organize the article by starting with possible causes for the explosion followed by problems created by the explosion and ending with solutions to the problem. The solutions may then be compared on effectiveness, cost, and implementation timeframe. These text structures have been explored by numerous experts (e.g., Armbruster, Anderson, & Ostertag, 1987; Paris, Cross, & Lipson, 1984; Pressley & McCormick, 1995; Vaughn, 2015; Williams et al., 2004), mentioned by the National Reading Panel (1999), recommended in national (e.g., Common Core State Standards adopted by 42 states, National Governors Association Center, 2010), and state (e.g., Texas Educational Knowledge Standards) standards as an approach to improving reading comprehension.

The theoretical framework for the structure strategy shares many similarities with the construction-integration (CI; van dijk & Kintsch, 1983) and landscape (van den Broek, 2005) models of reading comprehension. Both models share components that children need to read information, identify main ideas, integrate the new information with their prior knowledge, and utilize the knowledge in inferences, elaboration, and application for full comprehension. They also share the notion of comprehension monitoring and cohesion.

However, the structure strategy is different from these models when explicated for classroom implementation of reading comprehension practices. The difference is in the structure strategy's use of text structure as the framework for scaffolding each comprehension component (e.g., summarizing and comprehension monitoring with text structure scaffolds), transparency for the learner, and efficiency. Typical reading comprehension curricula tracing their antecedents to the CI or landscape models start with vocabulary instruction, then move through skimming text, reading, looking for main ideas, summarizing, generating inferences, checking/monitoring understanding, and finally present the text structure of the passage as a separate and independent comprehension supporting activity. In contrast, the structure strategy presented by ITSS uses text structure to guide/scaffold the reading, select main ideas, summarize, infer, elaborate, apply knowledge, and monitor comprehension. ITSS also shows children how text structures are often *nested in real-life texts* and presents guidance on imposing structure when *no text signals are present*.

4 | DESCRIPTION OF THE WEB-BASED ITSS FOR THE STRUCTURE STRATEGY

ITSS uses an animated pedagogical agent named I.T. to model how to identify signalling words, classify text structure, write a main idea, construct a recall of text, generate inferences, and monitor comprehension. The structure strategy training implemented within ITSS teaches readers to

1 identify the overall top-level structure of expository text (such as comparison, problem, and solution) by identifying signalling words (Meyer, 1975) used in text to explicitly cue these structures (such as "in contrast" and "on the other hand" for the comparison structure). Students click on signalling words within a passage and receive feedback on their answers. Once the signalling words are identified, students are asked to type which text structure is being used by the authors. Again, they receive feedback on their responses. A pop-up table is available to help students find signalling words commonly used;
2 write the main idea using patterns for each of the different text structures. For example, the comparison structure scaffold is _____ and _____ (two or more ideas) were compared on _____, _____, and _____ (number of issues compared). Within ITSS, students are scaffolded to select the most important ideas by using the pattern and then construct their main idea using custom text structure sentence stems. The software assesses the student responses taking into account misspellings, synonyms, keywords, and the hierarchical structure of the main idea;
3 organize their understanding and recall by using the structure and main idea. Students are asked to carefully read the passage again and press a finished reading button. The page turns and students are provided the main idea for the passage (i.e., student created main idea) and asked to recollect and write the recall of the passage using the appropriate signalling words and organization. Student responses are assessed carefully for the top-level structure, main ideas, details, and signalling words used. Feedback is provided based on the attempt and answer quality; and
4 infer, elaborate, apply, and monitor comprehension using text structures. In some lessons, students are asked to generate inferences, check their understanding, and apply their text structure knowledge in writing expository essays.

Utilizing these question types and providing modelling, practice tasks, immediate assessment, and feedback, ITSS guides the learners' construction of hierarchical memory representations of expository texts. Each student works individually with ITSS and can progress at their own pace. The teacher has opportunities to monitor the student progress through on-line and printed reports from the system but does not need to intervene unless the progress report notes unsuccessful efforts for the same questions. Research assistants from the team visited the schools biweekly to answer any questions the teachers may have. The standard ITSS version used in this research project has approximately 95 lessons that were presented to learners in the same sequence beginning with 12 comparison text structure lessons followed by problem and solution, cause and effect, sequence, and description text structure lessons (Meyer & Wijekumar, 2007). ITSS provides explicit, systematic, consistent, and carefully designed instruction for children on selecting and encoding hierarchical memory of expository texts from multiple domains (e.g., science and social studies).

4.1 | Research questions

The purpose of this study was to examine whether web-based instruction for the structure strategy can improve reading comprehension of fourth- and fifth-grade struggling readers as measured by standardized and researcher-designed measures. The research questions were as follows:

1 Do fourth- and fifth-grade struggling readers in classrooms using the ITSS delivery of the structure strategy as a partial substitute for the standard language arts curriculum outperform struggling readers in control classrooms on a standardized measure of reading comprehension?
2 Do fourth- and fifth-grade struggling readers in classrooms using the ITSS delivery of the structure strategy as a partial substitute for the standard language arts curriculum outperform struggling readers in control classrooms on researcher-designed measures of reading comprehension?

5 | METHOD

5.1 | Research design

A multisite cluster-randomized trial was planned and implemented in fourth- and fifth-grade classrooms in rural and suburban areas of the north-eastern part of the United States. Classrooms within each school were randomly assigned to ITSS or control groups, thus maintaining curricular consistency between both groups.

5.2 | Participants

A planned recruitment effort was conducted by the Project Director and Laboratory Extension Specialists at a large Research I university in the north-east. A volunteer sample of 45 schools (22 rural and 23 suburban) participated in the study with 128 fifth-grade classrooms and 131 fourth-grade classrooms. Participating schools had an average of 15:1 student to teacher ratio in both settings. This number was based on data reported on the school websites and included the special education teachers in number of teachers per grade level. Based on the classroom roster numbers, the student to teacher ratio was 24:1. Overall school level expenditures for rural schools was $12,145 per student and the suburban schools was $12,037 per student. The diversity of student populations at both rural (8% minority) and suburban schools (14% minority) was limited. Both locales (rural = 39% and suburban = 44%) had higher numbers of students eligible to receive a free or reduced price lunch that serves as a proxy for socio-economic levels.

After the school leaders had signed the memorandum of understanding, the team met with all fourth- and fifth-grade teachers in the participating schools and presented information about the research project. All teachers consented to participate in the study. Random assignment was conducted by the methodologist prior to the beginning of the school year. Each school mailed consent forms to parents of all students at the fourth- and fifth-grade levels prior to notification of random assignment. Approximately, 2% of parents opted not to allow their children to participate in the study.

As this study focused on struggling readers, the study sample included all participating students who scored below the 25th percentile on the pretest of the standardized Gray Silent Reading Test (GSRT; Wiederholt & Blalock, 2000). We opted to use the 25th percentile because many research projects have used that cut-off (e.g., Eason, Goldberg, Young, Geist, & Cutting, 2012; Etmanskie, Partanen, & Siegel, 2016; Fuchs et al., 2019; Rønberg & Petersen, 2016; Shapiro et al., 2017) or the 30th percentile (Wanzek et al., 2017) for identifying struggling readers to receive interventions. The GSRT was used to select students because it is a standardized reading test with sound psychometric properties. It also provided norm-referenced grade equivalent scores, which allowed us to verify that the final struggling reader sample indeed all scored below their corresponding grade levels. The final Grade 4 sample included 725 students (42.8% of which were female) from 128 classrooms (with an average of 5.66 students per class) in 43 schools (48.8% of which were rural). The Grade 5 sample included 717 students (44.6% of which were female) from 127 classrooms (an average of 5.65 students per class) in 42 schools (50% of which were rural).

5.3 | Procedure

The research team scheduled pretesting sessions at the beginning of the academic year with all participating classrooms and conducted the tests in a noise-free setting. Students with permission from parents completed standardized and researcher-designed measures of reading comprehension. The tests were administered by the research team and teachers.

Both ITSS and control classrooms maintained the same amount of language arts instructional time (average 450 min each week or approximately 90 min each day).

The ITSS classrooms were asked to substitute 30–45 min of language arts instruction each week with work in the software. Students in the intervention condition actually used the web-based software for approximately 20–30 min each week for the academic year (see explanation in results). Usernames and passwords were printed on individual login sheets for each child. These login sheets were distributed by the teacher at the beginning of each computer session and collected back at the end of the session. Students used headphones while interacting with ITSS to listen to I.T. modelling how she/he would use the text structure to read and comprehend passages. I.T. also instructed children to answer questions about the passages (e.g., click on the signalling words in the passage) and provided immediate and helpful hints to each child.

Intervention classroom teachers were provided with a 2-hr professional development at the beginning of the academic year. The professional development covered the use of the software and most common challenges that students experience when using the software. The research team had research assistants who visited the schools biweekly to provide any support or answer any questions the teachers may have. The research assistants were present at the school for the start-up of the software.

Posttest measures of reading comprehension were administered at the end of the school year. Similar to the pretest administration, the posttests were administered by members of the research team in the presence of the teachers.

All control classroom teachers were furnished with the professional development at the conclusion of the posttests. All control classroom students were also given full access to the software after posttests were completed.

5.4 | Materials

Cognitive measures used in this research included standardized and researcher-designed measures of reading comprehension. The standardized test used a multiple-choice format and is considered a distal measure to the instruction provided in the intervention. The researcher-designed measures used a short-answer and fill-in-the-blank formats.

The researcher-designed measure uses a generative/productive test of students' knowledge about discourse markers, selecting important ideas while reading and generating a main idea, recalling the text (without the passage in view), and using the author's top-level structure. These constructs are frequently used in standardized tests of reading comprehension in a receptive format—multiple choice. Specifically, the main idea portion of the researcher-designed measure provides a proximal generative measure that is designed to elicit student knowledge about what is important to focus on while reading. Getting the "gist" while reading is widely used as a measure of reading comprehension. In this measure, the students have to understand what the author's organization is, generate signal words for fill-in-the-blank tasks, and generate their own main idea of the passage. This provides a proximal measure for the intervention where students are instructed to find signalling words, identify the text structure, and write main ideas for the passages to improve their comprehension.

5.5 | Reading comprehension outcome for research questions

The outcome measures included a standardized test of reading comprehension and researcher-designed measures on writing comparison main ideas (Co-Main Idea Quality), competency in using the comparison (Co-Competence), competence in using problem and solution text structures (PS-Competence), and a cloze task designed to elicit knowledge of signalling words (Signalling). Reliability estimates calculated based on data collected for this study were high (see details below).

5.5.1 | Standardized test of reading comprehension

Two equivalent forms of the GSRT (Wiederholt & Blalock, 2000) were administered during the data collection. Form B was administered at pretest and Form A was administered at posttest. The test consists of 13 narrative texts with

increasing difficulty levels. Each text has five multiple-choice questions. Scoring of the GSRT was done using the procedures defined in the manual. The GSRT adjusted scores were comparable across forms and were used for data analyses. Cronbach's alpha for Forms A and B of the GSRT was reasonably high (α = .88) based on the full sample.

5.5.2 | Experimenter-designed measures of reading comprehension

As noted above, this proximal measure uses productive/generative tasks for students to fill in signalling words and generate main ideas of texts. Two test forms created and tested in previous research studies (e.g., Wijekumar et al., 2012) were administered at pretest and posttest sessions. The focus of the measures was on the comparison and problem and solution text structures. The following constructs were measured using these two forms.

- Comparison signalling word knowledge—a fill-in-the-blank activity with four blank spaces in the comparison text structure passage scored by two trained raters algorithm (maximum score of 7 points for each blank with rules on scores for exact match signalling words earning a score of 7 and variations and misspelling earning fewer points). The pretest comparison passage was on two different types of monkeys and had 128 words, 15 sentences, and 96 idea unITSS. The posttest passage was on two different types of penguins and had the same numbers of words, idea unITSS, and equivalent scores. Both the monkeys and penguins passages had equivalent scores on readability, text structure, and signalling (see Meyer et al., 2010).
- Comparison main idea competence—Students read the above passage on monkeys or penguins and wrote a main idea with the passage in view. The main ideas were scored on a scale of 1 to 8 by two trained raters with high-interrater exact score agreements ranging from 0.88 to 0.99.
- Comparison competence—Students placed the passage inside an envelope and wrote a full recall of the text without consulting the text. This full recall of the text was transcribed and scored on a scale of 1 to 8 by two trained independent raters who were unaware of the student's research condition.
- Problem and solution competence—Students read a passage about dogs (at pretest) and rats (at posttest) and placed the paper inside an envelope. The students then wrote a full recall of the passage (without consulting the text). The two passages each had 98 words, 72 idea unITSS, and equivalent scores on measures of readability, text structure, and signalling. Each text presented a problem, a cause for the problem, and solutions to the problem. The article about rats was an authentic article, and the passage about dogs was developed with researched information to match the format and text structures. When writing a recall of the text, the most competent readers focus on all three components (i.e., cause, problem, and solution) and scored 7 or 8 on the measure. Students with a moderate understanding of text structures may use the author's text structure and present some components (e.g., the problem or solution) score 5 or 6 or use another text structure (e.g., comparison) scores 3 to 4. The least competent readers write some words from the passage (e.g., it was about rats) score 1 or 2. Interrater exact score agreements between two scorers for this free-recall task with the problem and solution set of texts ranged from 89% to 98%.

5.6 | Scoring

Two graduate students who were unaware of the research condition of participants scored the main idea and recall tasks for the comparison and problem and solution text structure competence. They were trained in the propositional analysis of ideas in text used in previous research studies (e.g., Meyer et al., 2010; Meyer, Brandt, & Bluth, 1980). Training included reviews of guidelines for each score, independent scoring of sample passages from previous studies, discussion and clarification of scores, and transferring those skills to this dataset. When the scoring of this dataset was completed by the two raters, 10% of the sample were randomly selected and checked by the Co-PIs. Interrater agreements of 92% for pretest and 93.3% for posttest main idea were established based on exact score matches. Similar scoring procedures resulted in interrater agreement of 99.1% on comparison competency for the

full recall task. The problem and solution competence was scored by the trained raters in a similar manner, and agreement was 97.5%. Signalling word scoring presented 97.5% exact score agreement among raters. These high-interrater agreements were likely due to the use of a rubric, rigorous training of raters, and perhaps partly the limited corpus of text presented to the students for the main idea and recalls (which are well defined would have much less variability than open-ended written essays).

5.7 | Data analysis

To determine if there were differences between struggling readers within the ITSS and control classrooms with respect to reading performance for each of the fourth and fifth grades, a three-level hierarchical linear model (HLM: Raudenbush & Bryk, 2002) was computed for each of the outcome measures (GSRT and researcher-designed measures of reading comprehension) by grade. In each of the HLM model, student-level predictors included gender (1 = female and 0 = male, grand-mean centred), GSRT pretest scores (group-mean centred), and experimenter-designed reading comprehension pretest scores (comparison competency ratings for all outcome measures except for signalling for which ITSS pretest scores were used instead[1]; group-mean centred). Classroom-level predictors included class-mean GSRT pretest scores (grand-mean centred), the corresponding class-mean experimenter-made reading comprehension pretest scores (grand-mean centred), and ITSS (dummy coded: 1 = ITSS experimental group and 0 = control group). The coefficient for ITSS was the focus of this study because it represented the adjusted difference between ITSS and control groups in the outcome scores while controlling for reading comprehension pretest scores and students' gender. Hedge's *g* effect size (ES) for the intervention (ITSS) was computed by dividing this adjusted difference (i.e., estimated coefficient for ITSS from the HLM model) by the student-level pooled standard deviation on the pretest, if available, or the student-level pooled standard deviation on outcome measure (when pretest was not available). Confidence intervals (95%) for effect sizes were also calculated by first estimating the intervals for noncentrality (based on the observed *t* statistics) and then converting the end points to the effect size metric.

6 | RESULTS

Descriptive statistics by experimental condition and grade level for the standardized GSRT measure are given in Table 1, and the corresponding descriptive statistics for the experimenter-designed measures are shown in Tables 2 and 3. There were no statistically significant differences between ITSS and control conditions on any of the pretest reading measures. That is, the experimental conditions were balanced with respect to the outcome measures of interest prior to the ITSS intervention. The percentage of female students was also not significantly different between ITSS and control conditions for Grade 4 (44.5% in ITSS and 40.7% in control) or Grade 5 (42.9% in ITSS and 46.3% in control).

Tables 4 and 5 present the full three-level HLM model estimates and standard errors for Grades 4 and 5, respectively. For fourth graders, the ITSS group scored 1.45 points (ES = 0.28, 95% CI [−0.10, 0.66]) higher than the control group on GSRT posttest after controlling for locale, gender, and reading pretest differences, although the difference was not statistically significant (see Table 4). On the comparison structure outcomes at the fourth grade, the ITSS group outperformed the control group on signalling (ES = 0.34, 95% CI [0.14, 0.54]), main idea quality (ES = 0.55, 95% CI [0.34, 0.76]), and comparison competence (ES = 0.28, 95% CI = [0.10, 0.47]) holding reading pretest scores and gender constant. On the problem and solution structure outcome, fourth graders who participated in ITSS also scored higher (ES = 0.24, 95% CI [0.04, 0.45]) than the control counterpart with reading pretest scores and gender controlled for. These fourth-grade students used shortened ITSS lessons to reduce the typing burden and only completed the signalling word and matrix version of the main idea task.

It is worth noting that the performance was better at fifth grade where students used the complete lessons. After adjusted for local, gender, and reading pretest differences, fifth graders who participated in ITSS outperformed those

TABLE 1 Student- and class-level descriptive statistics for the Gray Silent Reading Test (GSRT; Wiederholt & Blalock, 2000)

	Intelligent Tutoring System for the Text Structure Strategy			Control		
	n	*M*	*SD*	*n*	*M*	*SD*
Grade 4						
Class level						
Pretest	63	8.57	2.62	65	8.45	2.21
Posttest	60	20.69	7.53	65	18.95	6.33
Student level						
Pretest	380	8.15	5.14	345	8.23	5.14
Posttest	296	19.67	10.73	309	18.68	10.22
Grade 5						
Class level						
Pretest	64	14.27	3.33	63	14.23	3.25
Posttest	62	27.12	5.94	61	23.95	5.28
Student level						
Pretest	352	13.89	6.72	365	13.76	6.68
Posttest	258	26.54	10.66	319	23.57	11.04

TABLE 2 Class-level descriptive statistics for the experimenter-designed measures

	Intelligent Tutoring System for the Text Structure Strategy			Control		
Measure	*n*	*M*	*SD*	*n*	*M*	*SD*
Fourth grade						
Signalpr (Signalling pretest)	63	8.65	3.14	65	8.31	3.25
Monmi (Co-Main Idea Quality pretest)	59	1.37	0.47	57	1.44	0.50
Monrte (Co-Competence pretest)	61	1.45	1.14	63	1.46	0.88
Signalpo (Signalling posttest)	63	10.01	4.76	65	7.99	3.91
Pemirte (Co-Main Idea Quality posttest)	53	2.61	1.08	52	1.82	0.80
Penrcrte (Co-Competence posttest)	53	2.64	1.32	52	2.16	1.05
Ratpstre (PS-Competence posttest)	53	1.85	0.95	52	1.58	0.70
Fifth grade						
Signalpr (Signalling pretest)	64	10.61	4.03	63	10.31	3.28
Monmi (Co-Main Idea Quality pretest)	55	1.90	0.72	55	1.82	0.71
Monrte (Co-Competence pretest)	62	2.09	1.35	61	1.94	1.11
Signalpo (Signalling posttest)	62	12.66	5.44	61	10.16	4.72
Pemirte (Co-Main Idea Quality posttest)	54	2.95	1.09	50	2.23	0.75
Penrcrte (Co-Competence posttest)	54	3.62	1.51	50	2.94	1.28
Ratpstre (PS-Competence posttest)	54	2.59	1.33	50	2.23	0.81

who did not on GSRT posttest (ES = 0.52, 95% CI [0.21, 0.84]). On the comparison structure outcomes at the fifth grade, the ITSS group scored higher than the control group on signalling (ES = 0.45, 95% CI [0.23, 0.67]), main idea quality (ES = 0.46, 95% CI [0.23, 0.68]), and comparison competence (ES = 0.25, 95% CI [0.03, 0.46]), holding reading

TABLE 3 Student-level descriptive statistics for the experimenter-designed measures

	Intelligent Tutoring System for the Text Structure Strategy			Control		
Measure	*n*	*M*	*SD*	*n*	*M*	*SD*
Fourth grade						
Signalpr (Signalling pretest)	378	8.39	5.32	343	8.28	5.31
Monmi (Co-Main Idea Quality pretest)	349	1.35	0.96	303	1.46	1.04
Monrte (Co-Competence pretest)	342	1.43	1.57	309	1.50	1.56
Signalpo (Signalling posttest)	321	9.91	6.79	312	8.28	5.42
Pemirte (Co-Main Idea Quality posttest)	237	2.52	1.68	231	1.73	1.31
Penrcrte (Co-Competence posttest)	241	2.59	2.05	236	2.08	1.80
Ratpstre (PS-Competence posttest)	248	1.81	1.37	238	1.52	1.14
Fifth grade						
Signalpr (Signalling pretest)	352	10.55	5.79	361	10.43	5.56
Monmi (Co-Main Idea Quality pretest)	312	1.89	1.42	304	1.86	1.41
Monrte (Co-Competence pretest)	314	2.23	2.14	331	2.07	1.90
Signalpo (Signalling posttest)	301	12.74	7.94	325	10.50	6.63
Pemirte (Co-Main Idea Quality posttest)	264	2.87	1.72	273	2.25	1.50
Penrcrte (Co-Competence posttest)	265	3.47	2.40	274	2.85	2.15
Ratpstre (PS-Competence posttest)	264	2.45	1.92	278	2.17	1.56

pretest scores, gender, and locale constant. The effect of ITSS on problem and solution structure competence (ES = 0.17, 95% CI [−0.04, 0.39]) was not statistically significant for fifth graders after controlling for reading pretest scores, locale, and gender (see Table 5). Over 70% of the students who scored at the lowest 25th percentile did not complete any problem and solution lessons.

This efficacy study used random assignment of fourth and fifth-grade classrooms to standard ITSS program or business-as-usual control with samples of volunteering rural and suburban schools. There were no special adaptations or accommodations for children who were experiencing reading difficulties. In the completed efficacy study, students used the standard version of ITSS (where all students followed the same sequence of lessons) and used the system approximately 20 to 30 min once a week over the full academic year. The schools were asked to use the software for about 30 to 45 min each week. However, most school allocated 30 to 45 min for the students to move from classroom to the lab, and there was a lag before the students actually logged in once they were in the computer lab. As a result, the actual usage was 20–30 min. Teachers received 2 hr of PD at the beginning of the school year on the structure strategy and also about managing the computer laboratory time. The PD did not provide opportunities for teachers to learn the structure strategy in depth and practice skills in applying it within the classrooms (e.g., text structure-based discussions about reading content from school textbooks, modelling use of the strategy with school assignments).

7 | DISCUSSION

The results presented above show that the structure strategy delivered via the web-based ITSS has evidence of positive impact and has the potential to provide a sound vehicle for further advancing instruction for children with reading difficulties.

TABLE 4 Grade 4 HLM estimates (SEs)

	GSRT	Signalling	Co-Main Idea Quality	Co-Competence	PS-Competence
Fixed effects					
Intercept	19.02*** (0.77)	8.10*** (0.62)	1.75*** (0.12)	2.04*** (0.14)	1.47*** (0.10)
Rural	−0.93 (1.21)	−1.22 (1.11)	−0.10 (0.16)	0.03 (0.19)	−0.07 (0.14)
Class GSRT pretest	0.33 (0.15)	0.08 (0.10)	0.02 (0.02)	0.01 (0.02)	−0.01 (0.02)
Class Co-Competence pretest	−0.20 (0.69)	—	0.48** (0.23)	0.02 (0.14)	0.16 (0.11)
Class Signalling pretest	—	0.06 (0.17)	—	—	—
ITSS	1.45 (0.98)	1.83** (0.53)	0.83*** (0.15)	0.55** (0.18)	0.31** (0.13)
Female	0.12 (0.84)	0.44 (0.44)	0.12 (0.14)	0. 37** (0.17)	0.11 (0.12)
Student GSRT pretest	0.64*** (0.09)	0.28*** (0.05)	0.05** (0.02)	0.10*** (0.02)	0.04** (0.01)
Student Co-Competence pretest	1.48*** (0.31)	—	0.10 (0.08)	0.33*** (0.06)	0.06 (0.04)
Student Signalling pretest	—	0.24*** (0.05)	—	—	—
Random effects (variances of)					
Schools	3.46***	9.04***	0.00	0.00	0.00
Classrooms	6.30**	2.04**	0.06**	0.04**	0.08**
Students	85.23	24.78	2.07	3.04	1.41

Abbreviations: GSRT, Gray Silent Reading Test; HLM, hierarchical linear model; ITSS, Intelligent Tutoring System for the Text Structure Strategy.
**$p < .01$, ***$p < .001$.

The research reported here presents new evidence about the possible use of text structure strategy instruction for students scoring at the lowest 25% percentile on reading comprehension pretests. To our knowledge, this is also the first time a web-based tutor was used to deliver this text structure strategy instruction to this profile of learner. Both factors address some of the challenges related to helping struggling readers. This analysis shows that the web-based ITSS made statistically significant and positive impacts on comprehension-promoting activities such as writing a main idea and also on standardized measures of reading comprehension. The effect sizes are similar in magnitude and direction to those reported by Denton et al. (2006), Denton, Fletcher, Taylor, Barth, and Vaughn (2014), Vaughn et al. (2012), and Wanzek et al. (2017). These research studies are used in this discussion to place our findings in the context of current research with struggling readers and targeting reading comprehension (beyond the learning to read phase). It is important to note that most of these studies do not use technology-based solutions as we have done in the present study. However, the intervention components overlap between these studies and ours and thus make a good comparison for this discussion (e.g., reading strategies).

Denton et al. (2006) reported effect sizes ranging from −0.18 to 1.77 on multiple reading domains with the Phono-Graphix and Read Naturally interventions separately and effect sizes ranging from 0.84 to 1.53 on the same measures when the interventions were combined. Denton et al. (2014) found small to moderate effect sizes for explicit instruction compared with guided reading and typical school instruction on measures of decoding, comprehension, and fluency. Vaughn et al. (2012) found effect sizes of 1.2 for reading comprehension and 0.49 for word identification. Wanzek et al. (2017) found an effect size of 0.38 on latent reading comprehension measured by the standardized Gates-MagGinitie Reading Test after students used the Passport to Literacy intervention. Wanzek et al.

TABLE 5 Grade 5 HLM estimates (SEs)

	GSRT	Signalling	Co-Main Idea Quality	Co-Competence	PS-Competence
Fixed effects					
Intercept	23.61*** (0.74)	10.19*** (0.74)	2.23*** (0.13)	2.86*** (0.20)	2.15*** (0.14)
Rural	−0.10 (1.05)	−0.39 (1.35)	−0.58** (0.18)	−0.62** (0.29)	−0.41** (0.19)
Class GSRT pretest	0.24 (0.14)	0.12 (0.10)	−0.02 (0.03)	0.02 (0.04)	0.00 (0.03)
Class Co-Competence pretest	0.40 (0.55)	—	0.27 (0.22)	0.20 (0.21)	0.11 (0.15)
Class Signalling pretest	—	0.03 (0.19)	—	—	—
ITSS	3.51** (1.04)	2.55*** (0.61)	0.73*** (0.17)	0.56** (0.25)	0.31 (0.19)
Female	0.69 (0.94)	0.48 (0.52)	−0.00 (0.14)	0.08 (0.19)	0.11 (0.15)
Student GSRT pretest	0.37*** (0.08)	0.23*** (0.04)	0.04*** (0.01)	0.04** (0.02)	0.04** (0.01)
Student Co-Competence pretest	0.99*** (0.27)	—	0.19*** (0.05)	0.37*** (0.05)	0.22*** (0.04)
Student Signalling pretest	—	0.24*** (0.05)	—	—	—
Random effects (variances of)					
	0.05	13.71***	0.02	0.18	0.00
Classrooms	5.23	1.87	0.22**	0.55***	0.31***
Students	101.21	33.84	2.14	3.81	2.46

Abbreviations: GSRT, Gray Silent Reading Test; HLM, hierarchical linear model; ITSS, Intelligent Tutoring System for the Text Structure Strategy.
**$p < .01$., ***$p < .001$.

report that the Passport to Literacy comprehension component was delivered as Tier 1 whole class instruction for approximately 35 min each week. The results from this study show the effect size of 0.28 for fourth-grade struggling readers and higher performance (ES = 0.52) with fifth-grade students on the standardized GSRT. The intervention time on ITSS appears within the range reported by Wanzek et al. and therefore may represent an effective length for the reading comprehension intervention whether it be delivered by trained tutors as in the Wanzek study or the web-based ITSS.

Future studies to refine and study the efficacy of an intervention such as the ITSS should focus on utilizing pre-test measures that can differentiate struggling readers based on their decoding, fluency, and vocabulary knowledge (e.g., Denton et al., 2014). Additional surveys may be necessary to identify the specific reading comprehension strategies that these struggling readers use prior to the delivery of the intervention. These types of information combined with data gathered through the student interactions with the web-based ITSS (e.g., time on task and numbers of attempts for different questions) may allow researchers to replicate the current findings and present nuanced reporting of how well these systems may assist students with specific reading related problems. Based on the findings, the ITSSs may also be modified and enhanced to provide assistance for students based on their specific needs in addition to the text structure-based reading strategy presented for writing main ideas and generating inferences. Enhancements to ITSS may focus on helping students experiencing difficulties in decoding, fluency, vocabulary, attentional control, and self-regulation.

Although our study used a strong design and was implemented with rigour, there are some limitations in the present study. One important limitation is that we did not separate the individuals with and without reading related problems such as those with decoding, comprehension, fluency, and vocabulary problems. Students at the upper elementary grade may still experience decoding difficulties and that may have contributed to the findings. We used the 25th percentile cut-off to identify the struggling readers based on other reported research and did not administer any other measures on decoding, fluency, and vocabulary knowledge, which is commonly used for interventions with struggling readers. Gathering data about specific reading disabilities or individualized education plans from the participating schools and administering additional measures on reading component skills such as fluency and vocabulary would have provided more information to conduct a more nuanced analysis about the impacts of the ITSS intervention. Finally, these research studies are based on a volunteer sample of schools from rural and suburban settings in the north-east United States, and information about the population of learners are provided. However, the generalizability of the findings are limited due to the volunteer sample of participants. Follow-up studies with different populations of students from different demographic profiles can increase the generalizability of findings. Finally, the study did use a within school random assignment of students to intervention or control groups, and it is likely that both groups received similar interventions for struggling readers within the school language arts curricula. However, we did not document what types of interventions were provided to the struggling readers in the intervention and control classrooms outside of this intervention.

ENDNOTE

[1] We used Signalling pretest as a covariate for Signalling posttest because understanding signalling words is a more basic word-level skill that could not be well captured by higher level reading competency measures.

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How to cite this article: Wijekumar K, Meyer BJ, Lei P, Beerwinkle AL, Joshi M. Supplementing teacher knowledge using web-based Intelligent Tutoring System for the Text Structure Strategy to improve content area reading comprehension with fourth- and fifth-grade struggling readers. *Dyslexia*. 2020;26:120–136. https://doi.org/10.1002/dys.1634