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Scaffolding learning of language structures with visual-syntactic text formatting

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Abstract
The current study examines the effects of digital scaffolding on the English literacy of fourth- and sixth-grade students. A total of 1085 native English-speaking and language minority students from 25 treatment classes and 20 control classes across three school districts participated in this study for one school year. Treatment students read their English language arts and social studies text in visual-syntactic text format (VSTF) on their laptops and control students read the regular block format of the textbook either on their laptops or in print. Observations and interviews revealed that VSTF reading facilitated instruction processes and student learning in reading activities. The results of California Standard Tests (CST) before and after the treatment revealed that sixth-graders who received syntactic scaffolding outperformed control students on the composite CST score. In particular, reading in VSTF benefited the treatment students in three CST sub-categories: word analysis, written conventions and writing strategies. This study suggests that future research should investigate instructional strategies that support reading and writing development of adolescents, including at-risk students, using syntactic scaffolding.

Introduction

Effective communication depends not only on the words we use but also on verbal and nonverbal cues. In oral communication, such cues typically include pauses, word stress and gestures, along with changes in pitch, pacing and flow. Written communication, however, conveys few of the cues that suggest information about the structures and meanings of texts, and it depends largely on punctuation and limited orthographic conventions (eg, italics, underlining or bold typeface). These punctuation and typographic emphases can help with comprehension but may occasionally lead the reader to misunderstand the underlying language structures.

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Practitioner Notes

What is already known about this topic

- Linguistic knowledge (morphology, syntax) plays an important role in students' reading development.
- Language arts classrooms rarely address the development of students' linguistic knowledge.
- Tools using natural language processing technology may facilitate instruction on language structures.

What this paper adds

- A syntactic scaffolding tool providing greater visibility to complex language structure is presented and its effectiveness is examined among a linguistically diverse student population.
- This tool is observed to facilitate instruction processes and student engagement in reading activities.
- This tool produces positive effects on students' standardized language arts assessment, especially for sixth-graders who are exposed to texts that are longer and more complex both syntactically and lexically.

Implication for practice and/or policy

- With the integration of this tool, teachers may seamlessly focus on language structures within their language arts curriculum.
- School districts and educational stakeholders interested in supporting the unique learning needs for adolescent students may consider incorporating this tool into teacher professional development.
- As regards this tool, or other digital scaffolding tools like it, policymakers should be considered when making recommendations for teaching adolescents.

Knowledge of morphology (ie, patterns of meaning at the level of words and affixes) and knowledge of syntax (ie, patterns for combining words into phrases and sentences) play a critical role in this meaning-making process. However, language arts classrooms rarely address the development of students' linguistic knowledge, partially because many public-school teachers are not professionally prepared to teach language structures (Fillmore & Snow, 2000; Scarcella, 2003).

To address this issue, this paper aims to explore how technology can be used as a tool to facilitate the learning and teaching of reading by highlighting the structures of language through scaffolding. Specifically, we argue that visual-syntactic text formatting (VSTF)—natural language processing technology that parses sentences and presents them in meaningful segments—presents a novel method for learning syntactic structures. This specific text presentation technology makes syntactic structures explicit without abridging the content of texts. Such explicit presentation is hypothesized to help readers better understand texts both by enhancing the understanding of syntactic structures and by supporting the learning of vocabulary in context (eg, morphological knowledge). This hypothesis will be further discussed below.

Information processing and reading

Proficient reading requires effective orchestration of many different skills (Perfetti & Stafura, 2014). Chunking, also called *parsing,* is a reading strategy that can help a reader group words in

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a sentence into short meaningful phrases. This strategy helps readers understand how words, phrases and clauses combine to convey meaning, allowing readers to anticipate what comes next and thus avoid confusion (LeVasseur, Macaruso, & Shankweiler, 2008). Morphological and syntactic knowledge is necessary for readers to correctly parse words into phrases or clauses, although typographical signs and punctuation may provide some support for parsing (Hirotani, Frazier, & Rayner, 2006; Stine-Morrow *et al.*, 2010). Eye movement studies have found that with growing skill, readers increasingly parse and process texts at clause and sentence boundaries (Tiffin-Richards & Schroeder, 2018). In contrast, poor readers rarely parse words into phrases or clauses (Fuchs, Fuchs, Hosp, & Jenkins, 2001).

An ability to effectively parse sentences not only helps readers understand the structure of sentences but also supports them in analyzing and inferring words from context. For example, interpreting the meaning of *bear* as either "animal" or "carry" necessitates form-meaning association and the ability to analyze the structure of the sentence where the word appears. Skillful readers can not only distinguish between multiple meanings of the same word using context clues but can also extract word meanings using both phonological (sound segments) and morphological (meaningful units) information. In particular, identifying morphological structure requires syntactic awareness (Nagy & Scott, 2000). For instance, *works* can be divided into two morphemes, *work* and *s*. Derivational suffixes, such as *–s* in *works*, give crucial help in grasping meanings of new words, by facilitating identification of this syntactic role of a suffixed word in a sentence. By and large, syntactic knowledge plays an important part in developing vocabulary knowledge as it closely relates to building both morphological awareness and form-meaning mapping.

Technological scaffolding

Prior technological scaffolding efforts

Various forms of advanced technologies have developed to facilitate teaching and learning of language structures, including content modification, format adjustment and automatic error correction (for an extensive review, see Anderson-Inman & Horney, 2007). Text modification, either by simplifying or concretizing content, is a common way to support language learners (Oh, 2001). Modified texts are typically written to ease lexical or syntactic demands on the reader, and may also contain greater redundancies and explanations (Kuo, 1993). Thus, modified texts are often lexically, syntactically and rhetorically less dense than authentic texts. However, text modification may also limit the overall coherence of the original texts and reduce students' exposure to important vocabulary and text structures; thus, it may not be an ideal solution for supporting struggling readers (Crossley, Louwerse, McCarthy, & McNamara, 2007).

Researchers have also examined adjusting the format as a way to scaffold reading comprehension and student mastery of language. These alterations have taken the form of simple changes in letters, line space and capitalization (Marks & Taylor, 1966) or the insertion of additional spaces between phrases (Bever, Jandreau, Burwell, Kaplan, & Zaenen, 1990; Jandreau & Bever, 1992). These methods can help parse sentences or direct students' attention to specific linguistic forms without changing the content of the text. Thus, format modification has the potential to make text more comprehensible for struggling readers while preserving the lexical and syntactic integrity of the original text. However, the effects of format modification have been mixed. While a number of studies have found that format modifications may support English learners' understanding of English texts (Lee, 2007; Lee & Huang, 2008; Simard, 2009), others report that simple format modifications, such as underlined text and bolded letters, may have little or no effect on language learning (Leow, 1997; Overstreet, 1998). The mixed findings may reflect the nature of the modifications themselves. For example, modifications such as bolding verbs and separating

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phrases with spacing may draw students' attention to particular word classes but typically do not illustrate the underlying language structures of those phrases.

Visual-syntactic text formatting

Another text alternative is VSTF, a method used to illustrate natural linguistic structures. VSTF technology automatically parses digital texts according to syntactic criteria at the phrase level. Lines are also limited in length so as to optimize human eye span and scanning capability. As the bottom diagram in Figure 1 (Park & Warschauer, 2016) reveals, VSTF reformats and presents the texts on digital devices to emphasize phrasing, hierarchically indenting short syntactic units. Thus, text in VSTF text is presented in short lines, with subordinate phrases and clauses indented. The result is a cascaded format, similar to a poem, which facilitates students' ability to see and implicitly learn the underlying syntactic structure of the text (Walker, Schloss, Fletcher, Vogel, & Walker, 2005). The top of Figure 1 shows syntactically complex text in traditional block format. In the center, its complexity is represented graphically with some clauses nested within larger ones. The bottom of Figure 1 shows the same text in VSTF format, with the hierarchical

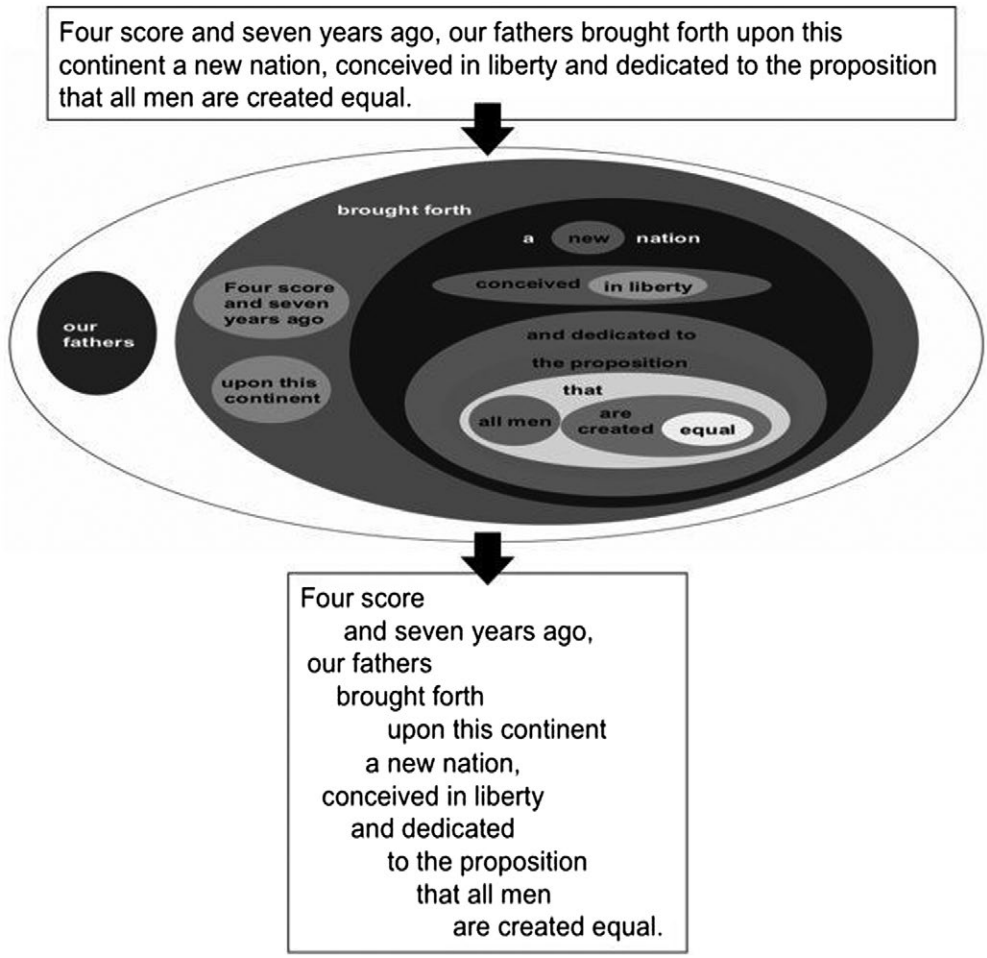

Figure 1: Text converted into visual-syntactic text formatting (Park & Warschauer, 2016)

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arrangement of phrases and clauses. This cascading text format highlights the text's meaning and syntactic structures, making it easier for students to parse. This meaning-based segmentation may facilitate the construction of mental models (Stine-Morrow *et al.*, 2010; Tiffin-Richards & Schroeder, 2018), thereby allowing students to develop more cohesive and richer representations of the text (Perfetti & Stafura, 2014).

The effects of this distinctive presentation have been examined in terms of reading comprehension, speed, retention and proficiency (Walker & Vogel, 2005; Walker *et al.*, 2005, 2007). In one study, 48 college students read three passages from computer screens either in standard block format or in VSTF (Walker *et al.*, 2005). Participants answered comprehension questions with 40% greater accuracy for the passages read in VSTF compared to those read in block format. Further, participants read the passages 20% faster with the VSTF presentation. Thus, VSTF led to gains in both reading efficiency and comprehension for college students. The effects of VSTF were also investigated among high school students for their reading retention in content courses (Walker & Vogel, 2005; Walker *et al.*, 2007). For example, 10th grade students who read their history texts in VSTF showed greater improvement in their unit and final exams throughout the school year as compared to their control peers. Overall, the effect size of the difference in exams in the second half of the year (.55) was larger than the effect size of the differences in the first half (.38). In these studies, the positive impact on reading proficiency is evidenced by the results of state standardized tests, the Measure of Academic Progress Test by the Northwest Educational Association (NWEA). A total of 384 sixth through eighth graders, and 184 ninth and tenth graders, took the reading comprehension tests of the NWEA, in which passages are all formatted in block text. The analysis of changes between the NWEA at the beginning of the school year and the NWEA at the end of the school year showed that VSTF readers made greater improvements than did their counterparts in the block format condition.

Despite large effect sizes reported in the aforementioned studies with VSTF, some weaknesses in research design, including risk of selection bias (Walker & Vogel, 2005) and carry-over effects (Walker *et al.*, 2005), limit the generalizability of these studies. To address these limitations,

Table 1: Student demographics by grade

	Full sample	*Fourth-grade*	*Sixth-grade*
Female	.502	.497	.507
Ethnicity			
Black	.035	.047	.024
White	.392	.499	.287
Asian	.152	.129	.175
Hispanic	.356	.243	.465
Other	.100	.129	.072
NSLP	.351	.200	.498
Disability	.066	.071	.062
Language proficiency			
ELL	.144	.093	.193
English only	.642	.785	.504
IFEP	.078	.050	.105
RFEP	.135	.071	.198
Observations	1085	535	550

Note. NSLP, National School Lunch Program (free or reduced-price lunch); ELL, English language learners; IFEP, Initial fluent English proficiency; RFEP, Reclassified fluent English proficiency.

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Table 2: Student demographics by grade and condition

	Fourth grade			*Sixth grade*		
	Treatment	*Control*	*Diff*	*Treatment*	*Control*	*Diff*
CST2011	50.400	49.484		55.149	55.388	
	(10.362)	(10.298)		(13.081)	(12.792)	
Female	.498	.496		.485	.542	
Ethnicity						
Black	.042	.052		.030	.014	
White	.484	.516		.292	.280	
Asian	.137	.120		.173	.178	
Hispanic	.239	.248		.449	.491	
Other	.140	.116		.086	.051	
NSLP	.175	.228		.488	.514	
Disability	.074	.068		.063	.061	
Language proficiency						
ELL	.088	.100		.208	.168	
English only	.800	.768		.536	.453	
IFEP	.063	.036		.068	.164	***
RFEP	.049	.096	*	.188	.215	
Observations	285	250		336	214	

Note. Standard deviation in parentheses.
NSLP, National School Lunch Program (free or reduced-price lunch); ELL, English language learners; IFEP, Initial fluent English proficiency; RFEP, Reclassified fluent English proficiency.
*Statistically significant difference between treatment and control at $p < .05$ level.
***$p < .001$ level.

we conducted a large randomized trial of the VSTF software in an effort to answer two specific research questions:

1. Does reading in VSTF positively influence students' reading performance in terms of vocabulary knowledge and sentence structures?
2. Are there heterogeneous treatment effects among participants from different grade levels?

Material and methods

Participants

The participants were drawn from the fourth- and sixth-grade classrooms of 25 schools in three suburban school districts in southern California, and the sample is a mixed population in terms of social class and language proficiency levels.

A total of 45 teachers in laptop classes were recruited to participate on a voluntary basis during the 2011–2012 academic year. Although a total of 1324 students participated, only 1085 students took both pre- and post-tests. In order to compare competing models, it was necessary to create a data set that included only students with valid data on variables. The sample was gender balanced. Student language proficiency levels were based on the designation system in California, where students are classified into one of the four categories: English-only, English language learners (ELL), initial fluent English proficiency (IFEP) and reclassified fluent English proficiency (RFEP). English-only refers to students who speak English as the primary language, while ELL, IFEP and RFEP refer to students who speak English as a second language (ESL). Among the ESL students, IFEP and RFEP students have higher English proficiency than ELL students, as

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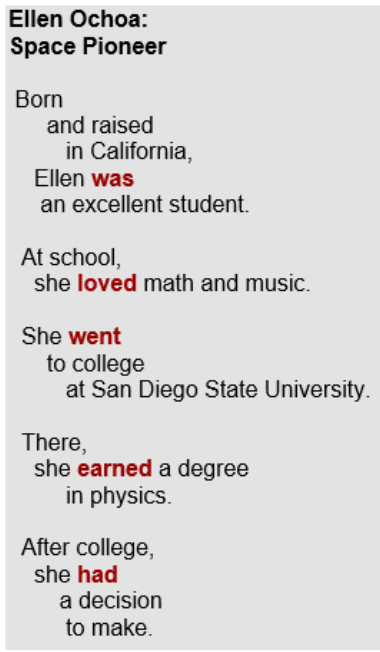
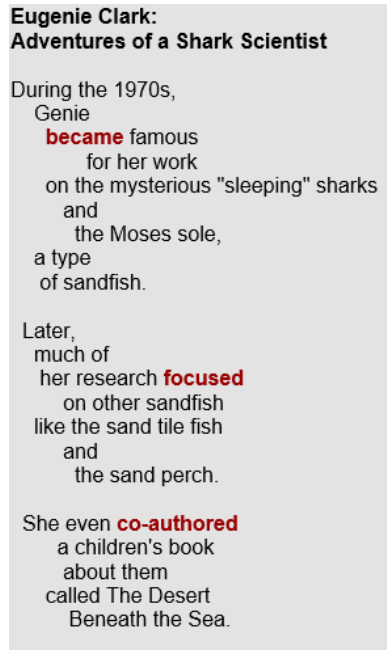
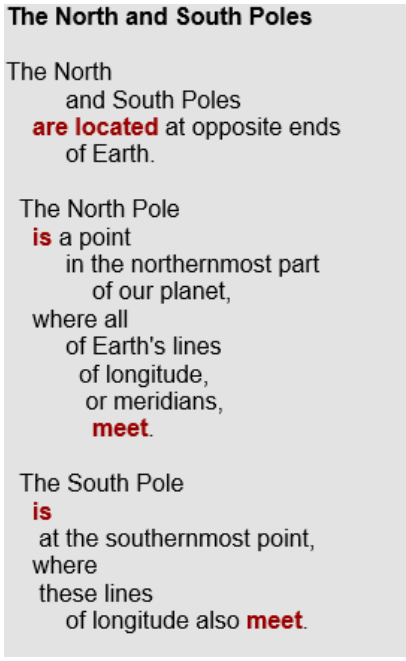


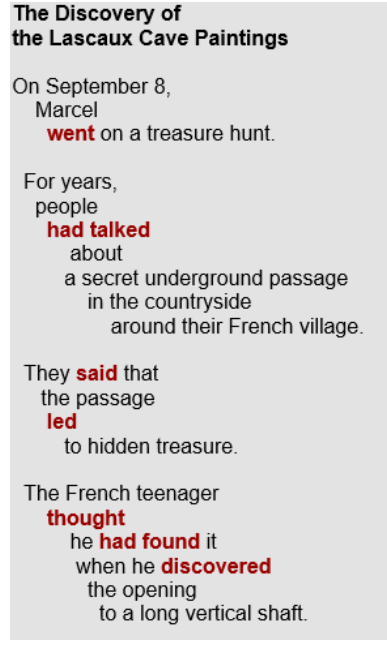
a. Fourth grade ELA text



b. Sixth grade ELA text



c. Fourth grade social studies text



d. Sixth grade social studies text

Figure 2: (a) fourth-grade ELA text; (b) sixth-grade ELA text; (c) fourth-grade social studies text; (d) sixth-grade social studies text

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determined by meeting the fluency criteria of the California English Language Development Test. In our analytic sample, 36% students were classified as ESL, including 14% ELL, 8% IFEP and 14% RFEP. Table 1 describes the demographic characteristics of the participants in detail.

Instructional context

The study was carried out in fourth- and sixth-grade English language arts and social studies classes. The language arts curriculum was aligned with district and state-adopted reading–language arts programs and was tied to State Content Standards for English Language Arts (California State Board of Education, 1998a). Students received instruction for approximately 2 hours daily, which emphasized systematic, explicit, skills instruction in reading and writing, and were asked to read and comprehend a wide variety of grade-level-appropriate literature. The social studies curriculum was aligned with the History-Social Science Content Standards for California Public Schools (California State Board of Education, 1998b). The curriculum required students to read and write about historical texts that were featured in the district's grade-level textbooks. The textbooks emphasized historical thinking and helped students gain the content literacy skills needed to understand important primary sources.

Design

A quasi-experimental design was used for this study, in which 25 of the 45 participating teachers were randomly assigned to either treatment or control group. Of the participating fourth graders, 285 students (53%) received VSTF treatment as compared to 250 students (47%), who read in traditional text format. Among the sixth graders, 336 (61%) received VSTF treatment as compared to 214 students (39%), who read in traditional text format.

The comparison of baseline characteristics between the treatment and control sample is presented in Table 2. For fourth-grade sample, with the exception of less students were reclassified fluent English proficient (RFEP, $\chi^2 = 4.44$, $p < .05$), students in both conditions were very similar demographically and in their achievement on the previous year's state assessment of English Language Arts. For sixth-grade sample, all baseline demographics and achievement were matched except that the treatment sample had less students who were initially designated as fluent English proficient (IFEP, $\chi^2 = 12.53$, $p < .001$). All of the participants were tested on their CST ELA at the end of the school year.

Treatment (VSTF) condition

The grade-level ELA and social studies textbooks were converted to a VSTF format (text only, no graphics) in each district. Figure 2a–d presents examples of VSTF texts used in the study.

All students in the treatment condition read the VSTF version of their textbooks on their laptop for one school year. Students received the typical standards-based instruction, but read each of their texts using the VSTF format for the assigned amount of time per week, which ranged between 30 to 120 minutes per the teacher's instruction ($M = 74.56$, $SD = 33.23$). The treatment lasted one academic year (approximately 25 weeks).

Control condition

Students in control classrooms also received the typical standards-based instruction for the same length of time as the treatment students. As compared to their treatment group peers, the control students read their textbook in regular block format, either on their laptops or in print. In most cases, the traditional textbook was chosen rather than the digital textbook. Like

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the treatment students, they also read their textbooks for the amount of time assigned to them by their teachers, which ranged between 65 and 130 minutes a week ($M = 88.62$, $SD = 20.31$).

Fidelity of treatment

In the treatment classrooms, the fidelity of teacher implementation and user experiences were obtained in three ways: classroom observations, teachers' logs and teacher interviews at the end of the school year.

Observation. All of the experiment classes were observed by researchers three times during the year. Strategies and comments both from teachers and students were logged during every observation, and are expected to give insights into using the system, both for program developers who are still looking for improvement, as well as for researchers who are expecting to see that users' experiences confirm their theoretical hypotheses.

Teachers' log. Treatment teachers recorded how long their students read texts in their classes for three designated weeks. According to the teacher logs, students read ELA texts for nearly 80 minutes a week on average.

Interview. Treatment teachers attended a 90-minute debriefing meeting and group interview, held at the end of the school year, which was audio-recorded and then transcribed. Teachers' reports in the meetings were expected to complement the information gained from observations, helping researchers make better sense of classroom implementation and students' performance.

Procedure

Near the end of the school year, all of the students took the California Standard Tests (CST), which served as a post-test for the study and were compared with CST results from the previous year. The same assessments were administered in the control group as in the treatment group, though the control teachers had no observation sessions or meetings, but instead reported their students' reading time for the three designated weeks and responded to an email survey regarding their implementation methods.

Measures

English language arts performance in CST

In order to examine the treatment effect, we used the composite score in the reading battery of the CST, which is based on California content standards. All of the test passages were formatted in a conventional block pattern on paper. Appendix A1 presents raw composite scores of CST before and after the intervention by condition. As CST results are not vertically equated across grade levels, we standardized the scores within the grade level using the sample mean and standard deviation for fourth and sixth grade, respectively.

English Language Arts Subtests in CST

The CST measures a broad range of language skills, some of which may be more or less influenced by the treatment. To explore this possibility further, analyses were run using individual CST strands. The subtests of the CST items focused on each of the following literacy skills: (1) word analysis, (2) reading comprehension, (3) literary response and analysis, (4) written conventions and (5) writing strategies. In *the word analysis subtest*, students are asked to use their knowledge of word origins and word relations, as well as word, sentence and paragraph clues to

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determine meaning. Reading grade-level appropriate narrative and expository texts for *the reading comprehension subtest*, students describe, connect and criticize the essential ideas, arguments and perspectives of the text using their knowledge of text structure, organization, purpose and related topics. In *the literary response and analysis subtest*, students read and respond to historically or culturally significant works of literature. The questions in *the written conventions subtest* represent the ways in which a command of Standard English conventions appropriate to the grade level is assessed, such as sentence structure, grammar, punctuation, capitalization and spelling. *The writing strategies subtest* has questions that assess students' ability to revise a flawed text into a clear, coherent and focused essay. Appendix A1 presents raw scores of CST subtests before and after the intervention by condition.

Subtest scores were also standardized within the grade level using the sample mean and standard deviation for fourth and sixth grades, respectively.

Analyses and results

Teaching and learning process

Interview and observation were used to contextualize the use and perceptions of this tools utility for supporting teaching and learning process.

Facilitating instruction

Initially, there was a period of difficulty for both teachers and students in getting used to the new text format. However, when asked during their debriefing meetings, a majority of teachers indicated that they would use VSTF again for their future instruction, as many of their students preferred the digital VSTF-reading to textbook-reading and were appreciative of a format that allows personalized colors and font sizes for texts.

One common theme mentioned by teachers was that VSTF helped students to concentrate in reading. The narrower page layout, with a fewer number of words per page than a normal textbook, especially benefits low-proficiency students "who otherwise immediately turn off on a story because of its length and the number of words that they see," according to a teacher from District A. Other teachers were quick to point out that VSTF stimulated students to read more closely and carefully, rather than just skimming through texts, which is a required skill for those who wish to acquire and deeply understand increasing amounts of content.

Teachers also pointed out that VSTF was especially helpful for low-proficiency students in paired reading, in which students read aloud to their partner. With VSTF, low-proficiency students were lost less often and read faster than they would in the regular format version. Teachers attributed this benefit to the sentence structure of VSTF and alternate paragraph colors in VSTF. These features made paired reading using the VSTF version "funner and easier" compared to the text in regular format, as one student explained.

Student learning

Classroom observations suggested that students' attitude toward the program was generally not positive initially. Many students did not like repeatedly clicking in order to progress through reading on their laptops. Despite this initial reluctance, students increasingly became more involved and at ease in using the program. With the VSTF texts, students were able to customize text styles to meet their needs. For example, one student stated that she was able to absorb more information at a quicker rate when reading in VSTF than when reading regular textbooks. This feature especially benefited those with visual disabilities. One teacher said of a student with visual impairment: "She was able to blow it up digitally which helped her vision a lot".

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Table 3: Effects on standardized CST 2012 composite score

	Fourth grade		Sixth grade	
	CST 2012		CST 2012	
	b	*SE*	*b*	*SE*
Treatment	−.001	(.050)	.072†	(.043)
Female	.040	(.050)	.076	(.043)
Black	−.304*	(.144)	−.247	(.165)
White	−.129	(.095)	.107	(.105)
Asian	.051	(.114)	.073	(.112)
Hispanic	−.217*	(.101)	−.052	(.103)
NSLP	−.285***	(.070)	−.186**	(.058)
Disability	−.200*	(.097)	−.172*	(.087)
ELL	−.158	(.130)	−.235**	(.076)
English only	−.106	(.109)	−.135*	(.067)
IFEP	−.205	(.146)	−.039	(.079)
CST 2011	.657***	(.030)	.782***	(.027)
District fixed-effects	Inc.		Inc.	
Constant	.356**	(.135)	.108	(.124)
Observations	535		550	
R-squared	.607		.771	

Note. Values in parentheses are standard errors.
†$p < .10$.
*$p < .05$.
**$p < .01$.
***$p < .0$.

Teachers also acknowledged positive changes in student literacy skills. A few teachers mentioned that their students started to recognize sentence structures during reading. For example, a teacher commented that some students in her class started to "read in phrases" as opposed to reading phonetically. In addition, this positive change in syntactic awareness was also manifested in writing activities. One day an ELL student even wrote her own passage in VSTF style, saying that she wanted to parse out her sentences.

Learning outcomes

The impact of VSTF was estimated using regressions with district fixed-effects to compare the outcomes of the students in the treatment and the control groups. Student demographics and pre-test scores were included in the regressions as covariates.

Composite score on ELA of the CST

Table 3 displays the fixed-effects regression results of treatment effects, for fourth grade and sixth grade. VSTF produces positive effects only on sixth graders but not fourth graders. In the sixth-grade sample, treatment students did better than control student ($b = .07$, $p < .1$), and the effect size is marginally significant. However, for the fourth-grade sample, students in treatment and control groups performed almost the same ($b = .00$).

No significant interactions were found with respect to whether students speak English as a first language (English-only) or as a second language (ELL, IFEP and RFEP). In other words, students

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who speak English as second language received the same benefits (in sixth grade) or lack of benefit (in fourth grade) as their English-only counterparts. We further restricted our analytic sample to ESL students and tested whether the treatment effects differ across language proficiency levels (Table 4). Among sixth graders, we found that lower proficiency language learners (ELLs) received greater benefits than higher proficiency second language speakers (IFEPs and RFEPs).

English language arts subtests

Table 5 shows the regression analyses predicting the outcome on each subtest of the CST for fourth- and sixth-grade students.

The right five columns of Table 5 show the results of the regression analyses for the outcome of each subtest of the CST for sixth-grade students. The VSTF treatment yielded significant gains on three subtests: word analysis ($b = .11$, $p < .05$), written conventions ($b = .12$, $p < .05$) and writing strategies ($b = .13$, $p < .05$), but not for the reading comprehension and literary response subtests. The left five columns of Table 5 show the results for fourth-grade students. Like the overall English Language Arts scores, the VSTF treatment did not affect fourth-grade students' performance on any of the five subtests.

Discussion

This study explores the use of VSTF to support the process of teaching and learning language arts. Because VSTF makes syntactic boundaries more salient and highlights the hierarchical structure of clauses and phrases within sentences, it may assist students in parsing and constructing meaning from texts (Tiffin-Richards & Schroeder, 2018). In particular, VSTF was a good fit for reading aloud with partners or as a class, as VSTF segments phrases and alternates colors for each sentence, indicating where students can take turns. This feature also meets the

Table 4: Effects on standardized CST 2012 composite score by english proficiency level among sixth graders

	Higher proficiency ESL (IFEP and RFEP)		*Lower proficiency ESL (ELL)*	
	CST 2012		*CST 2012*	
	b	*SE*	*b*	*SE*
Treatment	−.034	(.062)	.237†	(.121)
Female	.079	(.063)	.174	(.116)
White	.259	(.256)	.138	(.545)
Asian	.226	(.205)	.079	(.467)
Hispanic	−.024	(.212)	.034	(.431)
NSLP	.072	(.087)	−.339	(.255)
Disability	.139	(.184)	−.019	(.249)
CST 2011	.815***	(.051)	.579***	(.060)
Constant	−.092	(.209)	−.433	(.450)
Observations	168		106	
R-squared	.703		.543	

Note. Values in parentheses are standard errors.
†$p < .10$.
*$p < .05$.
**$p < .01$.
***$p < .0$.

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Table 5: Effects on standardized CST 2012 subtests

	Fourth grade					Sixth grade				
	Word analysis	*Reading comp*	*Literary response*	*Written conv*	*Writing strategies*	*Word analysis*	*Reading comp*	*Literary response*	*Written conv*	*Writing strategies*
Treatment	−.027	−.012	−.010	.058	−.005	.112*	.03	−.11	.123*	.126*
	(.055)	(.064)	(.049)	(.064)	(.063)	(.055)	(.056)	(.059)	(.061)	(.054)
Female	.051	−.022	−.026	.150*	−.037	−.025	.112*	.09	.105	.039
	(.056)	(.065)	(.050)	(.065)	(.063)	(.055)	(.056)	(.058)	(.060)	(.054)
Black	−.366*	−.064	−.022	−.407*	−.337	−.366	−.068	−.349	−.207	−.164
	(.161)	(.186)	(.143)	(.186)	(.182)	(.212)	(.217)	(.225)	(.234)	(.210)
White	−.135	−.097	−.003	−.104	−.192	.059	.190	.087	−.103	.176
	(.106)	(.123)	(.094)	(.123)	(.120)	(.135)	(.138)	(.143)	(.148)	(.133)
Asian	−.101	−.008	.290*	.048	−.047	.017	.109	−.047	.042	.142
	(.127)	(.147)	(.113)	(.147)	(.144)	(.144)	(.147)	(.152)	(.158)	(.142)
Hispanic	−.139	−.121	−.080	−.167	−.358**	−.087	.013	.007	−.209	.020
	(.113)	(.130)	(.100)	(.130)	(.128)	(.133)	(.136)	(.141)	(.146)	(.131)
NSLP	−.289***	−.223*	−.107	−.311***	−.255**	−.157*	−.137	−.195*	−.147	−.178*
	(.078)	(.090)	(.069)	(.090)	(.088)	(.075)	(.076)	(.079)	(.082)	(.074)
Disability	−.148	−.123	−.192*	−.142	−.236	−.172	−.11	−.124	−.323**	−.053
	(.108)	(.125)	(.096)	(.125)	(.123)	(.112)	(.115)	(.119)	(.124)	(.111)
ELL	−.123	−.080	−.256*	−.181	−.064	−.335***	−.148	−.094	−.239*	−.207*
	(.145)	(.168)	(.129)	(.168)	(.165)	(.097)	(.099)	(.103)	(.107)	(.096)
English only	−.074	−.080	−.002	−.218	−.156	−.037	−.11	.123	−.289**	−.208*
	(.121)	(.140)	(.108)	(.140)	(.137)	(.086)	(.088)	(.091)	(.095)	(.085)
IFEP	−.060	−.304	−.259	−.243	−.052	.059	.043	−.068	−.091	−.111
	(.164)	(.189)	(.146)	(.189)	(.185)	(.102)	(.104)	(.108)	(.112)	(.100)
CST 2011	.590***	.623***	.387***	.610***	.622***	.650***	.696***	.662***	.624***	.726***
	(.034)	(.039)	(.030)	(.039)	(.038)	(.035)	(.035)	(.037)	(.038)	(.034)
District fixed-effects	Inc.	Inc.	Inc.	Inc.	Inc.	Inc.	Inc.	Inc.	Inc.	Inc.
Constant	.335*	.233	−.079	.266	.425*	.131	−.017	.067	.277	.059
	(.151)	(.174)	(.134)	(.174)	(.170)	−.16	−.163	−.169	−.176	−.157
Observations	535	535	535	535	535	550	550	550	550	550
R-squared	.486	.424	.397	.453	.463	.618	.599	.567	.534	.635

Note. Values in parentheses are standard errors.
$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

needs of students with disabilities, many of whom may have difficulties taking in information from compressed regular texts. Some advanced readers also found that VSTF is a more efficient way to take in information than regular block texts.

The first question we examined was whether VSTF aids understanding of sentence and text structures and inference of word meanings from context. Although the treatment effects were not universal across both grade levels, students in sixth grade showed an overall improvement in English language arts achievement after the treatment. This improvement may best attributed to gains in vocabulary analysis, written conventions and writing strategies. First, performance on the written conventions is closely and directly related to syntactic knowledge, as this subtest requires knowledge of sentence structure, grammar, punctuation, capitalization and spelling. In addition, it appears that students were able to deal with both simple and complex sentence structures and made use of textual support to analyze word meanings and relations. Increased vocabulary analysis skills and improved knowledge of written conventions, in turn, led to better performance on the writing strategies subtest, especially in terms of precise use of vocabulary to develop a topic, knowledge of effective organizational patterns and ability to revise writing for improvement of organization. Performance on this subtest represents knowledge of vocabulary analysis and language structures rather than writing abilities, as this subtest does not require the ability to write an essay, but rather the ability to choose the best option when revising a flawed text. These results support our hypothesis that syntactic scaffolding helps increase vocabulary and syntactic knowledge.

Secondly, we asked whether the effects of VSTF would vary developmentally. We found VSTF led to significant gains for older students, in sixth grade, but not for students in fourth grade. This is not surprising for two reasons. First, eye tracking studies have shown that wrap-up processes, whereby individuals pause at clause and sentence breaks for meaning construction and integration, increase developmentally (Tiffin-Richards & Schroeder, 2018). Thus, sixth-grade students would be expected to make greater use of the syntactic structures highlighted by VSTF. Second, sixth-grade texts are longer and more complex both syntactically and lexically than fourth-grade texts (see discussion in Warschauer, 2006). Whereas VSTF may make explicit the dense and complex syntactic structures used in sixth-grade texts, the fourth-grade texts may be sufficiently accessible to students. Thus, VSTF may provide little additional benefit by making explicit linguistic structures that are already accessible in the fourth-grade texts. Indeed, although VSTF has been found in previous research to be an effective tool with middle school (Walker & Vogel, 2005), high school (Walker *et al.*, 2007) and university students (Walker *et al.*, 2005; Warschauer, Park, & Walker, 2011), it had not previously been studied in earlier than sixth grade. This study supports prior research indicating a positive effect with sixth-grade students (Walker & Vogel, 2005), but suggests that fourth grade may be too early to reap the benefits of VSTF.

There are two main limitations associated with the treatment. First of all, the design of this study aimed to compare the effects of two different text formats on reading performance. Although both treatment and control students have access to digital textbooks, control teachers frequently used paper texts instead of digital texts, while treatment students read the VSTF version on their laptop. Given that computers provide certain types of scaffolding (eg, enlarging print), the VSTF effect may be confounded with the modality of reading (computer-based vs. text-based). However, it seems unreasonable to conclude that the modality drove the effects rather than VSTF because passages on the pre- and post-tests were formatted in block text on paper, which might have worked in favor of paper text users rather than VSTF readers. Second, the initial technical problems in implementing the VSTF texts in some of the treatment classrooms might have affected the variability of study results. A few classrooms could not solve this issue for more than a month, which might have caused discomfort using VSTF among those teachers and students later in the experiment.

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There is also a limitation concerning an assessment measure employed in this study. While control teachers completed teacher logs and an interview, they were excluded in observation sessions. That is because we focused on fidelity of the treatment that observation in the treatment classrooms would confirm. However, as observations revealed interesting findings (eg, active collaboration in reading tasks, engagement of low-performing students), it would have been of value to compare these behaviors with teaching practices in control classrooms. That way, we could have demonstrated whether this active participation of learners is related with VSTF reading.

Conclusion

Despite some general recognition that students' ability to parse syntax is important for reading comprehension in early adolescence, very few high-quality intervention studies have evaluated the effects of specific approaches to teach syntax or to scaffold learning of syntax in the service of reading skills. This specific technological intervention is promising because it offers a potentially viable and scalable tool for teachers to integrate into their pedagogy.

Our study does not fully confirm the findings from prior research suggesting that the use of VSTF results in gains in reading, as no effect was found among fourth graders. However, our study did find that sixth graders benefit from using VSTF, and that among English language learners, particular benefits accrue to those of lowest proficiency. Additionally, our findings help identify which components of written language are most likely to be facilitated by VSTF: word analysis skills and knowledge of language structures. These benefits of VSTF could potentially be exploited through integration of the formatting in writing instruction, in addition to reading, a topic that we plan to investigate in future studies.

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Statements on open data, ethics and conflict of interest

The research data can be available upon request.

This research was carried out after receiving approval from the Institutional Review Board at University of California, Irvine.

All authors declare that there is no conflict of interest with respect to this study and the above manuscript.

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Appendix A: Descriptive statistics of outcome variables by grade and condition (raw scores)

	Fourth grade			*Sixth grade*		
	Full sample	*Treatment*	*Control*	*Full sample*	*Treatment*	*Control*
CST 2011	49.97	50.40	49.48	55.24	55.15	55.39
	(10.33)	(10.36)	(10.30)	(12.96)	(13.08)	(12.79)
Word analysis	17.70	17.83	17.55	10.62	10.60	10.64
	(3.35)	(3.35)	(3.35)	(2.60)	(2.63)	(2.56)
Reading comprehension	11.26	11.34	11.17	11.75	11.71	11.83
	(3.01)	(2.95)	(3.08)	(3.46)	(3.53)	(3.36)
Literary response	5.11	5.19	5.03	8.88	8.94	8.77
	(1.15)	(1.15)	(1.14)	(2.58)	(2.62)	(2.52)
Written conventions	10.53	10.60	10.45	12.68	12.65	12.74
	(2.79)	(2.79)	(2.80)	(3.00)	(3.06)	(2.90)
Writing strategies	5.37	5.47	5.25	11.32	11.25	11.42
	(1.96)	(1.98)	(1.94)	(3.23)	(3.21)	(3.27)
CST 2012	63.87	64.32	63.36	53.56	53.73	53.28
	(12.47)	(12.53)	(12.41)	(12.74)	(12.60)	(12.97)
Word analysis	15.38	15.45	15.31	9.72	9.80	9.59
	(2.92)	(2.93)	(2.92)	(2.55)	(2.49)	(2.65)
Reading comprehension	11.35	11.41	11.29	11.12	11.12	11.13
	(2.62)	(2.59)	(2.66)	(3.49)	(3.55)	(3.41)
Literary response	6.13	6.17	6.09	8.66	8.54	8.84
	(1.94)	(1.94)	(1.95)	(2.32)	(2.35)	(2.28)
Written conventions	13.64	13.83	13.43	12.12	12.21	11.98
	(3.21)	(3.28)	(3.12)	(2.71)	(2.64)	(2.81)
Writing strategies	10.42	10.52	10.30	11.94	12.07	11.74
	(3.16)	(3.20)	(3.12)	(3.57)	(3.49)	(3.70)
Observations	535	285	250	550	336	214

Note. Standard deviation in parentheses.

CST, California Standardized Testing.

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