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Using latent transition analysis to identify effects of an intelligent tutoring system on reading comprehension of seventh-grade students

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Abstract

Latent transition analysis (LTA) was conducted on data from a recent cluster randomized controlled study of 1808 seventh-grade students' use of a web-based intelligent tutoring system (ITSS). This analysis goes beyond traditional variable-centered methods to focus on profiles of learners and changes in reading class membership between pre- and post-tests for students with and without receiving ITSS intervention. A four-class model was obtained, consisting of poor readers (class 1), delayed readers (class 2), proficient readers (class 3), and readers with specific deficits in problem and solution (class 4). Analysis showed that students receiving the ITSS intervention were more likely than students without the intervention to transition into the proficient class regardless of their initial reading performance profiles. However, the odds ratio of transitioning into the proficient class (as opposed to staying in the same class) in the ITSS condition, compared to the control, was the highest (4.29) for initial readers with deficits in problem and solution, followed by initial poor readers (1.66) and initial delayed readers (1.50). Findings indicated that students in the ITSS condition had larger reading improvement than students in the control condition, particularly for readers with initial deficits in problem and solution.

Keywords Text structure strategy · Latent transition analysis · Reading comprehension

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Introduction

Many children in the U.S. struggle with reading comprehension (NAEP, 2017). Sixty-three percent of students in grades 4 and 12 and 64% of students in grade 8 have reading scores at or below basic levels of performance (NAEP, 2017). The text structure strategy (TSS) is one approach designed to solve this problem by presenting instruction on selecting important information, writing main ideas, generating inferences, and monitoring comprehension by utilizing logical connections within the texts related to comparisons, problems and solutions, causes and effects, sequences, and descriptions (Meyer, 1975; Meyer & Poon, 2001). A recent cluster randomized controlled study examined if seventh-grade students using a web-based intelligent tutoring system (ITSS) to learn and apply the TSS outperformed control classroom students at posttest (Wijekumar, Meyer, & Lei, 2017). Results showed that there were statistically significant effects favoring the intervention classrooms on all standardized and researcher designed measures with the highest effect sizes reported for generating main ideas.

As the ITSS intervention continues to be refined and researchers attempt to promote uptake of the TSS in schools, important questions related to the difficulty of learning different text structures, student profiles in reading (i.e., students' comprehension of comparison vs. problem and solution texts) and whether the ITSS instruction promotes comprehension of all types of text structure passages for all profiles of learners remain unanswered. Answers to these types of questions can help further customize instruction within the web-based tutoring system and be responsive to practitioner needs for classroom instruction. However, the recent publication (Wijekumar et al., 2017) used the traditional variable-centered analysis method that showed the existence and size of intervention effects but failed to profile whether learners fall into certain groups (e.g., readers who were unable to comprehend comparison and problem and solution texts, readers who were able to comprehend one but not the other) and whether each group of students may have more salient intervention effects than other groups.

To overcome the drawbacks of the traditional variable-centered methods (e.g., lack of ability to profile learners based on multiple facets of comprehension), the present study adopted the latent profile analysis (LPA) and latent transition analysis (LTA) models for data analysis. Our study focused on first identifying profiles of learners on multiple text structure measures followed by testing the effectiveness of ITSS via assessing the probability that ITSS changes students' reading comprehension class membership after use. First, latent profiles of learners are established using two indicator variables of reading comprehension in each of the three types of texts. The indicator variables are a) top-level structure of the student's main idea and b) competency of using text structure based on a full recall, and the three types of texts are problem–solution, short comparison, and long comparison texts. Therefore, there are 6 continuous indicator variables available to determine the class memberships in the pre-test and post-test conditions for both intervention and control classroom students. The number of memberships is determined using a series of conventional fit indices (e.g., AIC, BIC) and classification quality indicator (entropy value).

Then the LTA is used to answer questions related to the types of individuals who stay within the same class or move after instruction and whether the probability of the transition differs based on the research conditions. Therefore, LTA can be used to answer the questions regarding the change by an intervention. In addition, the results of LTA can also inform researchers the detailed profiles of learners and for whom the intervention works best.

Context of study

As students move into the middle grades, they are increasingly expected to use reading as a means of learning new information, thus adding an additional layer of complexity to the reading process. This reading to learn expectation extends beyond students' English/Language Arts classes and into their science, social studies, and even math courses. In these content areas, students are not only expected to fully comprehend expository texts about topics such as erosion, colonization, and polygons, but they are also expected to use their comprehension to help them skillfully learn from what they have read. However, students enter middle school with limited exposure to expository texts having mostly been taught to read narrative texts (Williams & Pao, 2011). Given the comprehension struggles of the majority of grade 4, 8, and 12 students on the NAEP test and the limited exposure to expository texts during the learning to read phase of reading development, students need a comprehension strategy that can be used with expository texts.

Text structure instruction has been successfully shown in multiple studies to improve reading comprehension of expository texts (Hebert, Bohaty, Nelson & Brown, 2016). Meyer (1987) suggests that instruction in text structure may help students for three reasons. One, understanding the structure of a text helps the reader understand the author's purpose. Two, the text's structure can be used to help the reader organize ideas by level of importance based on the author's purpose. Thus, text structures help readers to select important ideas and logically connect the ideas to promote comprehension. Three, the reader can save memory and processing time by using the same structure as the author rather than creating a wholly unique schema or searching for an appropriate existing schema.

The theoretical foundation of the TSS comes from the text structure model of reading comprehension. The model parallels the construction integration (CI) and landscape models in focusing on information in the text (i.e., textbase in CI) combined with prior knowledge thereby generating a powerful organized memory. Where the CI and landscape models differ from the text structure model is in the instructional application of the model. Specifically, the TSS subsumes and scaffolds all comprehension promoting activities such as selecting important information, generating a main idea, making inferences, and monitoring comprehension by using the five text structures and nested structures.

In a meta-analysis of 45 text structure instruction studies conducted with students in grades 1 through 12 in the years 1982 through 2015, Hebert et al. (2016) found an average weighted effect size of 0.57 favoring text structure strategy instruction. Additionally, Hebert and colleagues reported that 35 studies

showed overall positive effect sizes ranging from 0.06 to 2.81. The analysis found an effect size of 0.96 for eight studies involving only students with or at-risk for learning disabilities and an effect size of 0.57 for 11 studies that included measures of text structure maintenance (i.e. delayed posttests 1 day–3 months after posttest). These effect sizes support the use of text structure instruction to improve reading outcomes.

As students advance into middle grades, science and social studies content focus on causes and effects, problems and solutions, and comparisons to promote higher-order thinking. In contrast to memorizing descriptions of content or sequences of dates, higher order thinking requires reading with an eye toward causes to a problem, comparing solution alternatives, and connecting solutions to the causes of the problems. Several of the Next Generation Science Standards (NGSS) for grades 6–8 require students to think in terms of problems, solutions, causes, and effects.

For example, one NGSS standard states that students "apply Newton's Third Law to design a solution to a problem involving the motion of two colliding objects" (NGSS Lead States, 2013). To find a quality solution to the problem of two objects colliding, students must understand the causes and effects of the collision in terms of Newton's Third Law. Although lesson models such as the 5E model (engage, explore, explain, extend, and evaluate) encourage learning science concepts through hands-on activities, students still gain a great deal of science knowledge through reading (Kaldenberg, Watt, & Therrien, 2015; O'Reilly & McNamara, 2007). This means that students are likely to be required to read and comprehend information about Newton's laws prior to addressing this standard. Additionally, students must be able to read and think in terms of cause-effect and problem–solution to research the problems associated with various collisions (e.g. car crash, wind blowing objected into each other, body to body).

Thus, this study focused on seventh-grade students learning and using the comparison text structure followed by the problem and solution, and cause and effect structures. This LPA and LTA analysis focused on two constructs measured (i.e., top-level structure and competence in using the text structures) using science and social studies texts utilizing a problem and solution, short comparison, and long comparison passages. Instruction about text structures described next focused on approximately 12 comparison text structure lessons followed by 10 problem and solution and 10 cause and effect lessons.

Description of the web-based text structure strategy instruction

The text structure strategy teaches students to utilize the logical connections of a text to improve their comprehension. Instruction begins with learning how signaling words (i.e., similar, problem, as a result) can be used to identify the organizational structure of the text (i.e., comparison, problem and solution, cause and effect). Learners then use the text structure scaffolds to identify important information from the text (e.g., what is the cause of the problem? What are the effects?). Using custom sentence stems for each text structure, learners write the

main idea (e.g., cause is _____ and the effects are ____, ____, and ____). Combining the main idea and signaling words, learners monitor their comprehension and learn how to remember more information from the text.

The web-based intelligent tutoring system for the structure strategy (ITSS) used an animated pedagogical agent named I.T. to teach students how to find signaling words, select important ideas, logically connect the ideas, write main ideas, monitor comprehension, and recall information based on the structure of the text. ITSS has been found to be an effective way of teaching the structure strategy with statistically significant and positive effects favoring the intervention classrooms on standardized and researcher designed measures of comprehension (Wijekumar, Meyer, & Lei, 2012; Wijekumar et al., 2014; Wijekumar, Meyer, & Lei, 2017). ITSS also teaches students how to predict the author's intention to inform or persuade using text structure. ITSS provides consistent high-quality instruction, covers many content areas, explicitly demonstrates the application of text structures to improve reading comprehension and recall, scaffolds students' reading with appropriate texts, and gives students immediate assessment and advanced/elaborated feedback (Meyer et al., 2010; Wijekumar et al., 2014).

The success of recent studies has been attributed to a deeper understanding of adapting text structures to the classroom setting and careful attention to reducing contradictions in instruction about main ideas (Wijekumar, Meyer, Lei, Hernandez, August, n.a.). One reason for the success of text structure instruction presented in these studies is that the structure strategy subsumes other components (i.e., summary, main idea, inference), which are sub-skills of reading comprehension. This strategic approach views reading comprehension as a "holistic system" rather than individual components and the learning and teaching process as adaptable and flexible, in comparison with the "traditional method" that requires students to learn by rote memorization, multiple drills, and automatization (Dole, Duffy, Roehler, & Pearson, 1991). Another way of stating the difference is that many previous approaches to reading comprehension focus on skills in isolation (e.g., main ideas detached from text structure) whereas the structure strategy focuses on main ideas linked to the text structure (e.g., Scott Foresman Reading Street, Texas Journeys, MacMillan).

As the research evidence continues to grow, so do the questions related to how students learn and use the different text structures and whether different text structures may present different challenges to learners. Researchers and practitioners may benefit from answers to questions that can further refine ITSS and promote the uptake of the TSS in classrooms. As noted in the introduction, the traditional variable-centered data analytic tools may be limited in understanding the complex multi-faceted nature of reading and new analytic tools may be useful to further study profiles of learners.

Alternative approach to data analysis

Multiple studies have shown the structure strategy is an efficient and effective reading comprehension approach (Meyer, Brandt, & Bluth 1980; Meyer et al. 2002; Meyer, Wijekumar, & Lin, 2011; Meyer et al., 2010; Meyer, Young, & Bartlett, 1989; Wijekumar, Meyer, & Lei, 2012; Wijekumar et al., 2014; Wijekumar, Meyer, & Lei, 2017). However, most studies used the traditional variable-centered analysis method, which fails to inform the multi-faceted profile of students' reading skill patterns. The magnitude of intervention effects is often measured by the "change" in test scores. The traditional method used in the reported studies show small to small effects on standardized measures and moderate effects on researcher designed measures. Unfortunately, those analyses do not provide a deeper understanding about the types of learners studied and whether they show different patterns of movement between their class profiles.

In this multi-site cluster randomized controlled study, seventh-grade students used a web-based intelligent tutoring system for structure strategy with the aim to improve their reading comprehension. The first part of analysis focused on identifying profiles of learners based on their performance on comparison and problem and solution comprehension tasks and LCA. In the second part we hypothesized that students who were in the intervention group would have a higher likelihood to move into a proficient class of students compared to those in the control group. To identify this intervention effect, we used the LTA model-a person-centered method. Research questions guiding the LTA analytic approach are:

1. What are the reading proficiency profiles of the seventh-grade students?
2. Do certain profiles of students (classes) have a higher transition probability to proficient status than others?
3. For students in the intervention and control groups, what are the transition probabilities from one reading profile to another between pre-and post-test time points?

Method

Participants

The participants in the current study were a sample of 1808 students enrolled in a large-scale randomized controlled trial study of the efficacy of the web-based ITSS. Seventh-grade classrooms within 25 rural and suburban schools were randomly assigned to intervention or control groups. A total of 1087 students were in the ITSS treatment group and 721 were in the control group. Approximately 42% of participants were eligible to receive a free or reduced price lunch and 8% were racial/ethnic minorities. Students in the intervention group received the intelligent web-based tutoring system for the structure strategy for 30–45 min per week as a partial substitute for the language arts curriculum, while students in the control group took the school's language arts courses as usual.

Measures

The focus of this study was on the students' ability to detect and use the comparison, problem and solution, and cause and effect text structures in their reading comprehension. Thus we focused on three researcher designed measures that were administered at both pre- and posttest. The measures were created by Meyer et al. (2010) and included two equivalent forms. Form 1 was administered at pre-test before starting ITSS and form 2 was administered after students completed the ITSS intervention. Both forms included a problem and solution text, a short comparison text, and a long comparison text. Both forms had the same number of words and idea units for each text.

Problem and Solution Passage: Students read the passage and tore out the page and placed it in an envelope and wrote a recall of the passage without consulting the passage. The recalls were scored for competency and top-level structure (TLS) in using the problem and solution text structure to recollect as much information as possible. Competency in using the problem and solution structure was scored from 1 to 8 with a score of 1 indicating there was no problem, no solution, no cause stated in the recall. A score of 8 meant that the problem, solution, and cause of the problem and how the cause was eliminated were presented within the recall.

A good problem and solution TLS meant a score of 9 (maximum possible points) and required a problem and solution with the stated cause. A 6 meant that the recall presented a problem and solution but not the solution mentioned in the passage. Scores of 7, 8, and 9 meant that the students used the appropriate signaling words (7—problem, 8—solution, and 9—both problem and solution). $_{\text{If}}$ students only provided a descriptive list of ideas about the passage with no signals indicating problem and/or solution scores of 2–4 were awarded. Scores of 4 or 5 were given to those that presented some connections between the problems and solutions without explicit signaling of the text structures.

Short comparison passage: students read a two-paragraph science passage comparing two different animals. Students were asked to place the passage inside the envelope and recall as much information about the passage and write a recall. The short comparison TLS and competence were scored similarly to the problem and solution scoring guidelines. The TLS scores ranged from 1 to 9 and the competence was scored from 1 to 8. In the short comparison text, the focus was on the two animals being compared and attribution of the factors to the correct animal.

Long Comparison Passage: A multi-paragraph social studies text was then presented to the learners. After reading, students were instructed to place the pages inside the envelope and then write a recall of the passage without consulting the text. Similar to the scoring of the short comparison recall, these recalls were scored for TLS and competency.

The researcher designed measures were scored by trained raters using the Meyer et al. (2010) scoring training guide that used a propositional analysis of the ideas in the text with a hierarchical content structure connecting the inter-relationships between the ideas. Sample texts were presented to scorers and practice sessions were guided by a senior researcher. All raters received extensive training and were blind to the research conditions of the participants. Within this procedure, raters practiced

scoring on a series of student responses from the same passages until they reached consensus. During the scoring of data, the raters were checked by an expert by verifying all scores during the training phase. Interrater reliability for all scores was very high ranging from .91 to .99. The descriptive statistics of all the measures were presented in Table 1.

Analytic strategy

Latent transition analysis (LTA) was used to identify the latent profiles of students' reading comprehension skills and estimate the transition probabilities from pretest to posttest profiles. The Latent Transition Analysis (LTA) model is the longitudinal extension of the Latent Profile Analysis (LPA) model, allowing the latent class membership to change over time (Collins & Lanza, 2010). In our study, the LTA model included a measurement model for the latent class variables at pre-test and post-test time points and a latent structure that modeled the associations between the latent class memberships and the treatment grouping variable (i.e., covariate). In other words, the LTA model focused on how the transitioning likelihood between the latent classes at the pre-test and post-test time points differed in treatment and control conditions. The transition probabilities are conditional probabilities [P(C2|C1)] for post-test time point classes (C2) given pre-test time point classes (C1). In our study, since treatment condition serves as a covariate between C1 and C2, the transition probabilities are the conditional probabilities [P(C2)|CG, C1] for post-test time point classes, given the pre-test time point classes (C1) and treatment conditions (CG).

Table 1 Means and standard deviations on reading measures

Measure	ITSS (n = 1087)				Control (n = 721)			
	Pretest		Posttest		Pretest		Posttest	
	M	SD	M	SD	M	SD	M	SD
Problem and solution text								
Top-level structure (PSTLS)	4.37	2.49	5.03	2.45	4.29	2.48	4.38	2.31
Competence (PSCPT)	3.68	2.08	5.00	2.62	3.71	2.03	4.44	2.51
Short comparison text								
Top-level structure (SCTLS)	5.46	1.87	6.56	2.02	5.36	1.88	5.81	1.84
Competence (SCCPT)	3.05	1.55	5.21	2.28	3.04	1.55	4.78	2.24
Long comparison text								
Top-level structure (LCTLS)	2.76	1.57	4.60	2.21	2.74	1.58	4.12	2.03
Competence (LCCPT)	1.54	1.13	2.74	1.67	1.49	1.05	2.41	1.51

ITSS intelligent tutoring system for the structure strategy

Restrictions on parameter estimation

First, we made the conditional independence assumption: The residual covariances between indicators were restricted to be zero, and variance and covariance structure were constrained to be identical across classes. Namely, the latent profile models were specified with a class-invariant variance–covariance structure and diagonal residual covariance matrix. The diagonal residual variance setting was consistent with the assumption of local independence in the classical LPA (Marsh, Lüdtke, Trautwein, & Morin, 2009). The class-invariant variance–covariance structure allows us to evaluate and interpret the identified latent profiles with respect to the item means only (Masyn, 2013).

Second, we also made the measure invariance assumption across the two time points. Measurement invariance can facilitate model identification and stabilize model estimation. As Collins and Lanza (2010, p. 212) argue, "… it is a good idea to constrain the item response probabilities in the LTA to be equal across time whenever it is reasonable to do so…" (i.e., measurement invariance). It is also applicable to LPA-based LTA in the current study.

LTA Model building

In our study, we first ran a series of LTA model enumeration from one latent class to six latent classes without covariate across the two time points using Latent Gold 5.1 (Vermunt & Magidson, 2016). As the purpose of our study is to examine the intervention effect of the ITSS method, ITSS participation is modeled as a covariate that impacts the transition probabilities between the two time points. The differences in transition probabilities between the control and ITSS indicates intervention effects. Hence, we also ran another series of model enumeration for LTA with the ITSS covariate. This approach also allowed us to check whether the addition of covariate would impact the model selection or not.

Model selection

To determine the optimal number of latent classes, we compared models with different number of latent classes and a decision was based upon both substantive interpretation and comparative fit indices. AIC, CAIC, BIC, SABIC are fit indices used to compare model fits, where a smaller value indicates better fit (for details see Morgan, 2015). We graphed the fit indices on the number of classes (i.e., the "elbow" plot) to help identify the "elbow" which indicates the preferred number of classes by the index in question. In addition, the entropy is used for model selection. Higher entropy indicates better classification solution or clearer delineation of classes.

Results

Latent profile of reading performance based on long comparison tasks, short comparison tasks, and problem solution

We ran a series of LTA models across two time points, which means the LPA models on each time point were estimated simultaneously. Moreover, measurement invariance was imposed across the two time points. Hence, the interpretations of the identified latent classes would be the same on both time points. Table 2 presents the goodness-of-fit indices for each model. AIC, CAIC, BIC, and SABIC indicated that the 6-class LTA without covariate had the best fit to data. However, in terms of model parsimony, the 6-class solution was not preferred, since two classes have almost identical profiles. We then compared the 4- with 5-class solution. The 4-class solution had higher entropy than the 5-class solution. Finally, the "elbow" plot of those relative model fit indices was clearly leveling off (the "elbow") at the 4 classes (see Fig. 1). Hence, the 4-class model was retained as the selected "best model". Results of the LTA with covariate had similar pattern, and the 4-class solution was retained as the "best model". The addition of covariate did not impact the model fit and selection.

Interpretation of the identified latent profiles of reading performance

Table 3 and Fig. 2 detailed the features of the identified latent profiles. Four salient latent classes were obtained: poor readers (class 1), delayed readers (class 2),

Table 2 Model fit information used for LTA model selection (need to be updated)

	BIC	AIC	CAIC	SABIC	Npar	Entropy
Latent transition model without covariate						
1-Class	93,115.03	93,049.03	93,127.03	93,076.90	12	1.00
2-Class	84,610.46	84,494.96	84,631.46	84,543.74	21	0.92
3-Class	81,792.86	81,616.86	81,824.86	81,691.19	32	0.99
4-Class	79,480.25	79,232.75	79,525.25	79,337.29	45	0.96
5-Class	78,412.12	78,082.12	78,472.12	78,221.50	60	0.95
6-Class	76,901.09	76,477.6	76,978.09	76,656.47	77	0.98
Latent transition model with covariate						
1-Class	93,115.03	93,049.03	93,127.03	93,076.90	12	1.00
2-Class	84,612.20	84,480.20	84,636.20	84,535.96	24	0.92
3-Class	81,832.42	81,612.43	81,872.42	81,705.34	40	0.99
4-Class	79,554.96	79,224.96	79,614.96	79,364.35	60	0.96
5-Class	78,540.51	78,078.51	78,624.51	78,273.64	84	0.95
6-Class	77,108.89	76,492.90	77,220.89	76,753.07	112	0.98

BIC Bayesian information criterion, *SABIC* sample size-adjusted Bayesian information criterion, *AIC* Akaike's information criterion, *CAIC* consistent Akaike's information criterion, *Npar* number of parameters

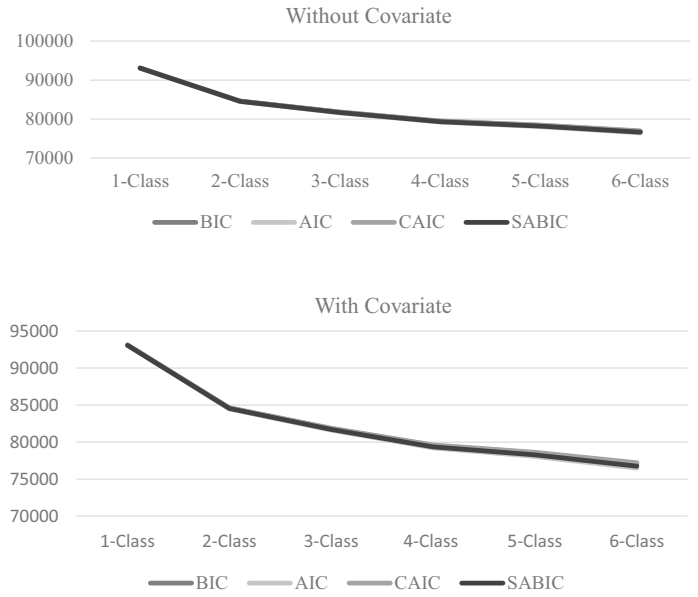

Fig. 1 Relative model fit indices for models with and without covariate. *BIC* Bayesian information criterion, *SABIC* sample size-adjusted Bayesian information criterion, *AIC* Akaike's information criterion, *CAIC* consistent Akaike's information criterion

proficient readers (class 3), and readers with specific deficits in problem and solution (class 4). Poor readers underperformed on all six measures compared with other latent classes. Delayed readers had relatively lower long comparison test performance in both top-level structure and competence measures, which indicated that students in this class were lagging behind their peers in other latent classes. The proficient readers outperformed the other three classes on all six measures. Finally, the fourth identified class included readers with specific deficits in problem and solution text structure. The descending ranking in terms of overall reading performance was proficient readers (class 3), readers with specific deficits in problem and solution task (class 4), delayed readers (class 2), and poor readers (class 1).

The prevalence of the latent profiles varied between the two time points (see Table 4). At pre-test, around 50% of the participants were classified as poor readers, while only approximately 10% of participants were proficient readers. Moreover, about 33% of students were classified as delayed readers, and only 6% of the students were those with specific deficits in problem and solution text structure. In contrast, at the post-test, about 21% of participants belonged to the proficient group, which is twice that at the pre-test

The proportion of poor readers was also reduced to 40% from the 50% at pre-test. The group size of delayed readers also became smaller at post-test. However, the proportion of readers with specific deficits in problem and solution increased to 10% from 6%. In summary, there was an overall upward movement trend in terms of reading performance from pre-test to post-test.

Table 3 Mean scores for each measure by latent profiles

Measure	Latent profiles											
	1. Poor readers			2. Delayed readers			3. Proficient readers			4. Readers with specific in P&S		
	est.	LL	UL	est.	LL	UL	est.	LL	UL	est.	LL	UL
Problem and solution text												
Top-level structure (PSTLS)	2.254	2.204	2.304	6.766	6.705	6.827	6.945	6.874	7.015	2.513	2.405	2.620
Competence (PSCPT)	2.341	2.260	2.422	5.604	5.507	5.700	6.640	6.527	6.753	2.891	2.728	3.054
Short comparison text												
Top-level structure (SCTLS)	4.880	4.783	4.976	6.022	5.912	6.131	7.169	7.043	7.295	6.362	6.176	6.549
Competence (SCCPT)	3.015	2.904	3.125	4.058	3.937	4.178	5.587	5.448	5.725	4.843	4.630	5.056
Long comparison text												
Top-level structure (LCTLS)	2.210	2.143	2.276	2.621	2.556	2.685	6.417	6.338	6.495	5.780	5.595	5.964
Competence (LCCPT)	1.102	1.058	1.145	1.344	1.297	1.391	4.137	4.081	4.193	3.564	3.417	3.711

The estimations were based on the model with a specification of a class-invariant variance–covariance structure and diagonal residual variance matrix

P&S problem and solution, *est.* estimates, *LL* lower limits for 95% CIs, *UL* lower limits for 95% CIs

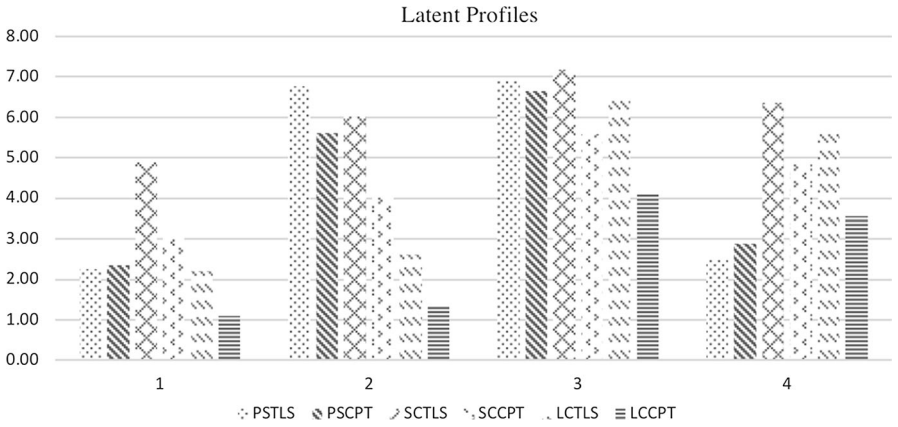

Fig. 2 Latent profiles of reading performance on pre-and post-tests. *PSTLS* problem and solution text (top-level structure), *PSCPT* problem and solution text (competence), *SCTLS* short comparison text (top-level structure), *SCCPT* short comparison text (competence), *LCTLS* long comparison text (top-level structure), *LCCPT* long comparison text (competence). 1 = Poor readers, 2 = delayed readers, 3 = proficient readers, 4 = readers with specific deficits in the problem and solution

Interpretation of ITSS intervention effect

To clearly specify the intervention effect of the ITSS instructional method, the LTA with treatment indicator (ITSS = 1, control = 0) as covariate was estimated. The likelihood of the mover or stayer in the latent class over time points conditional on intervention levels was used to gauge the magnitude of effect size. Results of LTA with covariate indicated positive association between intervention transition to higher performance classes for grade 7 students as shown in Table 4. In other words, the students in the intervention group were more likely to transition out of the lower performance class (e.g., readers with specific deficits in problem and solution) into the higher performance class (e.g., proficient readers) in comparison with students in the control group. For example, participants with specific deficits in problem and solution at pre-test had 0.092 probability of staying and 0.675 probability of moving to the proficient class after the intervention. In contrast, for participants in the control group, the likelihood of staying was 0.242 and the likelihood of moving to the proficient class was 0.414. We also compared the transitional probability for the students with specific deficits to become proficient readers in different conditions (ITSS vs. control), using the transitioning odds ratio (OR). The OR result was 4.29 (i.e., 0.675/0.092 divided by 0.414/0.242), which means for students with specific deficits in problem and solution, the estimated odds of moving to the proficient class (compared to staying) for the ITSS group was 4.29 times the corresponding odds for the control group. Moreover, it is noteworthy that the effect of ITSS varied depending on students' initial reading profile. The transitioning odds ratio (comparing ITSS vs. control condition) for poor readers and delayed readers to become proficient readers were 1.66 (0.205/0.408 divided by 0.147/0.485) and 1.50 (0.437/0.28 divided by 0.284/0.277), respectively, much lower than the corresponding transitioning odds

Table 4 Results of latent transition models

	Prevalence of latent profiles											
	1. Poor readers (%)			2. Delayed readers (%)			3. Proficient readers (%)			4. Readers with specific in P&S (%)		
Pre-test	50.73			33.43			9.78			6.05		
Post-test	40.32			28.40			21.20			10.08		
Combined	est.	LL	UL	est.	LL	UL	est.	LL	UL	est.	LL	UL
Transition probabilities (rows for pre-test, COLUMNS for post-test)												
1. Poor readers	0.441	0.406	0.475	0.229	0.201	0.257	0.181	0.155	0.207	0.150	0.123	0.176
2. Delayed readers	0.193	0.157	0.229	0.282	0.245	0.319	0.377	0.337	0.417	0.148	0.114	0.181
3. Proficient readers	0.048	0.011	0.086	0.130	0.077	0.182	0.749	0.680	0.817	0.073	0.029	0.118
4. Readers with specific deficits in P&S	0.105	0.042	0.169	0.174	0.097	0.250	0.578	0.479	0.676	0.144	0.077	0.210
Control												
1. Poor readers	**0.485**	0.434	0.535	0.233	0.189	0.276	0.147	0.110	0.185	0.135	0.097	0.173
2. Delayed readers	0.249	0.187	0.311	**0.277**	0.218	0.337	0.284	0.224	0.344	0.190	0.133	0.247
3. Proficient readers	0.057	−0.006	0.120	0.179	0.085	0.273	**0.686**	0.572	0.800	0.078	0.006	0.150
4. Readers with specific deficits in P&S	0.133	0.010	0.257	0.211	0.080	0.342	0.414	0.254	0.574	**0.242**	0.087	0.396
ITSS												
1. Poor readers	**0.408**	0.363	0.452	0.226	0.190	0.262	0.205	0.169	0.240	0.162	0.126	0.198
2. Delayed readers	0.155	0.114	0.196	**0.284**	0.237	0.332	0.437	0.384	0.489	0.124	0.086	0.163
3. Proficient readers	0.041	−0.004	0.086	0.098	0.038	0.158	**0.791**	0.708	0.874	0.070	0.013	0.128
4. Readers with specific deficits in P&S	0.083	0.014	0.153	0.150	0.057	0.243	0.675	0.555	0.795	**0.092**	0.016	0.168

The probabilities of being stayers are highlighted in boldface

P&S problem and solution, *est.* estimates, *LL* lower limits for 95% CIs, *UL* lower limits for 95% CIs

ratio for readers with initial deficits in problem and solution. In summary, ITSS appeared to have positive impact on improving students' reading performance in general as indicated by higher probabilities of transitioning to or staying in the proficient class after ITSS participation for all initial reading profiles. The effect of ITSS seemed to be particularly strong for students with initial deficits in the problem and solution text structure.

Discussion

The purpose of this study was to identify profiles of learners based on their comprehension of comparison and problem and solution text structures and examine the effect of ITSS on different groups of learners. ITSS is a web-based intelligent tutoring system designed to teach the text structure strategy to students. ITSS students are taught how to comprehend expository texts by selecting and encoding strategic memory, summarizing, inferring, elaborating, and monitoring comprehension (Wijekumar, Meyer, & Lei, 2017). The results show that students in the ITSS intervention group are more likely to progress to the proficient class in comparison to the control group without ITSS intervention, indicating that ITSS has a positive effect on students' reading comprehension skills. These results corroborated findings in recently published studies about ITSS at lower grade levels (Wijekumar et al., 2014, Wijekumar, Meyer, & Lei 2012).

In contrast to previous studies utilizing conventional analysis methods, the person-centered LTA method revealed four heterogeneous reading performance profiles for grade 7 students participated in this study. These reading performance profiles offer a more specific understanding of how students' progress after using the ITSS intervention. Further, these profiles are beneficial in helping researchers understand how to help students develop better reading in the content areas, because the profiles provide a more focused understanding of students' strengths and weaknesses related to comparison and problem and solution text structures that are very important to science and social studies learning in the middle grades.

Figure 2 shows interesting groupings with profile 1 students struggling with both text structures and slightly proficient in the short comparison passage (we called this the poor reader class). These students appear to struggle with any reading assignment given to them, as evidenced by their lack of ability to write a main idea for a short comparison passage that has a readability below their grade level. These students may be lacking foundational prerequisite skills related decoding and vocabulary. They may also need more practice with both the comparison and problem and solution text structures than students in other classes. They would also need practice in using the cause and effect text structure and be shown how to nest text structures where the cause is linked to the problem and solution. Overall, these students may need additional interventions focused on basic reading skills (e.g., vocabulary, decoding) and future research can focus on the specific difficulties these students face with regard to the prerequisite skills as well as the text structure-based comprehension.

Profile 2 students appear to be somewhat proficient in both problem and solution and short comparison texts but unable to comprehend the long comparison passage (we named this the delayed reader class). Students in the delayed reader class may have oscillating difficulties in their content area classes-doing well with smaller reading assignments but having difficulty when assignments get longer. The delayed readers' issues with the longer comparison passage on the surface appears to be an issue of stamina. However, considering that students are somewhat proficient with both text structures in shorter passages, the longer length of the long comparison passage may be overtaxing the students' working memory by requiring too much information to be held. The longer comparison passage, by virtue of being longer, may also include more difficult vocabulary than students are able to compensate for. As with the poor reader class, future research can focus on the specific difficulties the delayed reader class is facing.

Profile 4 students appear to have difficulty understanding the problem and solution text structure but can understand and use the comparison text structure passage (i.e., the class with deficits in problem and solution structure). These students are likely to benefit from focused problem and solution text structure instruction and extending it to include the cause for the problem. Competence in the problem and solution text structure is especially important in the content areas. As stated previous, several NGSS standards address cause and effect and problem and solution text structures as important logical connectors of comprehension. Although there are no specific history/social studies standards for the common core, several of the English Language Arts standards are focused on history/social studies and incorporate the need to be able to understand causes and effects and problems and solutions in texts. Students must be able to make the connection between causes, problems, and solutions as they read primary and secondary source texts.

Students in profile 3 appear to have the best overall understanding of both text structures (this is the class of proficient readers). These students are likely to find little difficulty with text structure-based comprehension in their content areas classes.

By examining the differences between intervention and control groups in transition probabilities to the proficient profile, we found that ITSS facilitated students' success in moving from initial classes with certain deficits (in both text structures, long comparison texts, or problem and solution texts) to the proficient class. ITSS intervention appears to be especially effective for students with specific deficits in problem and solution tasks initially. The intervention group also had a higher likelihood of staying in the proficient reader class than the control group.

This analysis has practical implications for further refining the ITSS or developers of other text structure interventions and can help practitioners also customize instruction to different profiles/classes of learners. As observed in the profiles, some students appear to struggle with just the problem and solution text structure and the science and social studies content areas can benefit from knowing how to use it. Therefore, diagnostic measures can be administered in the beginning of the

academic year and practitioners may emphasize how the text structure works. Showing students the utility of learning and using the cause-problem–solution nested structure may improve their understanding of science and social studies content. Similarly, within the ITSS a new adaptation path may gauge students' proficiency in each text structure and start instruction for students with the ones they struggle with first (e.g., instead of starting with comparison, start lessons with problem and solution).

In summary, by using the LTA analytic approach, we identified four underlying reading profiles and found that ITSS use resulted in a higher likelihood that students can move from profile 1, 2, and 4–3. Moreover, different from conventional methods, the Latent Profile and Transition Analyses enable researchers to identify positive and negative impacts of the intervention on reading comprehension. This approach provided a unique view about modeling intervention effects. Instead of comparing the means of related variables after the intervention, this person-centered approach focused on the transition and stability of class membership. Since each student can be located based on their class membership, researchers can easily profile the specific group.

Limitations

Similar to other studies, this LPA and LTA study also has its limitations. The measures used in this analysis focused on problem and solution and comparison text structures with seventh-grade students participating in a multi-site cluster randomized study. No information can be gleaned about student knowledge about other text structures based on these measures. Further, the current profiles generated information about four classes of students using these measures, no information was available about students decoding or vocabulary knowledge and those variables may have provided a richer profile of the students. To obtain a more precise and accurate reading profile, more measures should be added in future research studies. The measures used here asked students to write a main idea with the passage in view and recalls to passage without consulting the text. Other approaches to gathering information about how students understand comparison and problem and solution text structures may include multiple choice questions and be easy to administer. These other assessments of text structure knowledge may also provide additional information for such analyses.

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