Overcoming Barriers to Remote Learning: Computer Assisted Instruction to Enhance Mathematical Word Problem Solving

Aishwarya Nair1, Adam, K., Dubé1
1McGill University

Modern teaching and learning are heavily influenced by technology and its adoption into the classroom. With the advent of Apple Education and Google classrooms, the impact and efficacy of web-based and digital tools cannot be overlooked. With a sharp and unexpected move towards remote learning seen for all classrooms post-pandemic, we need to develop effective intervention programs that strategically integrate these tools in literacy and math instruction. This study tested the effectiveness of a mathematically enhanced reading program, Math CORPS, against a standard reading intervention using remote teaching modalities. Six students (age range 9.1-11.0, M = 10.2 years, 3 males) from grades four and five were selected for the online single case experimental design (SCED) study targeting math word problem comprehension using reading principles. A detailed visual analysis of data suggested that a contextually enhanced reading intervention led to greater gains in performance on mathematical word problems than a standard, best practices reading program. Effect size investigations using Baseline Corrected Tau method reveal moderate to large effects of the treatment (ES ranging from .643 to .743) on word problem solving. This may suggest that poor performance in math word problems is indicative of a contextual reading deficit rather than a general reading deficit and has the potential to influence math pedagogy using evidence-based technology tools.

**Keywords:** reading, word problems, online interventions, mathematics, comprehension

Integrating technology into classroom instruction is not a new concept by any measure. The use of various technological modalities in literacy and math instruction is ubiquitous. Studies have highlighted that the best outcomes are seen when teachers are provided with effective training and support in implementing technology-assisted instruction in their classrooms (McGlynn-Stewart et al., 2017; Voogt & McKenney, 2017). Technology integration is also seen to provide social and cognitive benefits for students when using effective programs (Archer et al., 2014; Savage et al., 2013). There is also greater potential for increased motivation for engagement due to the ‘gamified’ nature of some activities (Clark & Mayer, 2011; Flewitt, Messer, & Kucirkova, 2015), which further drives achievement (Evans et al., 2015). However, in the light of a global pandemic which led to a forced transition to remote learning for classrooms across the world, it is crucial that we identify effective intervention platforms that serve the needs of students in a vastly different teaching and learning landscape.

The current paper will illustrate the design and implementation of an online intervention for mathematical word problem solving, which adapts best-practice reading intervention principles. This program adapts empirically validated literacy strategies to address word problem solving. A single case experimental design (SCED) study was conducted to compare the effects of a contextually enhanced word problem intervention to a standard reading intervention for students in grades four and five.

**Barriers to Technology Adoption**

With the increased emphasis placed by schools on digital learning, what are some factors that affect learning acquisition? Significant attention has been placed on integrated or hybrid programs generating better outcomes than stand-alone digital ones (Savage, Nair, McBreen, & Wood, 2017). The opportunity to practice concepts in various settings seems to drive these results (Archer et al., 2014; Cassady & Smith, 2005). In a study conducted by Grant et al. (2012), it was found that the level of technological implementation was a significant predictor of improved literacy scores, with adaptation being most effective. This may be interpreted as a meaningful and intentional application of technology by connecting it to learning themes present in the classroom (Grant et al., 2012). Lack of access to evidence-based technology platforms is also a significant barrier to effective implementation in learning settings (Nikolopoulos & Gialamas, 2015; Savage et al., 2017)). It is therefore important to illustrate
how some web-based tools and open-access software can be utilized to create a wide range of meaningful activities that are guided by curriculum aims. The following sections will describe the theoretical foundations that guided the design and development of two digital intervention programs aimed at improving children’s word problem solving skills.

**Theoretical Foundations**

Capraro et al. (2012) propose a two-pronged model of reading-enhanced word problem solving. It describes two cognitive components- recognizing patterns (R) and generating patterns (G). The R component is based on direct instruction and practice (Blair et al., 2007). It focuses on vocabulary, word identification, and semantic/syntactic features of word problems. It highlights fluency as an important feature which leads to comprehension (Capraro et al., 2012). The G component focuses on story organization, background knowledge, and metacognition. Good readers and good mathematical problem solvers have in common one ability- monitoring their comprehension. Thus, this model and its specific constructs encourages the intervention to be less focused on deriving answers to problems and more on facilitating the application of cognitive components of reading and mathematics (Capraro et al., 2012). A concept map of elements influencing program design is illustrated in Figure 1.

**Math CORPS versus Standard Reading.**

The Contextual Reading and Problem Solving in Math (Math CORPS) program consists of three modules- Vocabulary, Context Training, and Comprehension. The Vocabulary module consists of common words found in Word Problems (WPs) for grades four and five. These terms were then grouped into change (so far, left, more), combine (altogether, total, in all), or compare (more than, less than) categories. Activities like word wall creation, exploring synonyms and antonyms, and other word properties were developed using web-based tools like Wordwall (https://wordwall.net/), a website that helps to create customized templates. Context Training module was designed to encourage schema identification. Digital graphic organizers were implemented during this phase. These were designed using Canva (https://www.canva.com/) - an online portal for graphic design. The Comprehension module introduced the acronym- “RIDES Check!” as a tool for comprehension monitoring. This stands for Read, Identify the type, Draw the figure, Explain the problem, Solve, Check your work. Digital design tools were accessed to create visual representations of schemas and diagrams. These diagrams incorporated effective comprehension strategies like summarizing, predicting, and inferencing (Afflerbach et al., 2017; Jones & Seilhamer, 2019) in an easy-to-remember form.

The Standard Reading program, on the other hand, was developed using an internet-based reading program called ABRACADABRA (https://literacy.concordia.ca/abra/en/), which was selected because of its content based on what constitutes effective reading interventions (Savage et al., 2009). This program provides explicit instruction through activities based on phonics, reading fluency, practicing expressions, and text comprehension tasks. It has been proven especially effective in phonemic instruction, listening comprehension, and vocabulary (Abrami et al., 2015). The Standard Reading program consisted of three modules- Decoding, Fluency, and Comprehension. The Decoding module used Blending Train, Auditory Segmenting, Word Matching, and Word Families activities. These tasks targeted sounding out, matching, and manipulating words. The Fluency module targeted Accuracy and Expression while reading. Students track the pronunciation of difficult words as well as identifying appropriate expression for passages. The Comprehension module used Summarizing, Prediction, and Comprehension Monitoring activities.

The following guiding questions inform the single case experimental study examining the impact of an enhanced intervention program-

1. Relative to standard best-practice reading program, will a technology-enhanced contextual reading program (Math CORPS) lead to better performance on math word problem solving?

**Method**

**Participants.** Participants were six students (age range 9.1-11.0, \( M = 10.2 \) years, 3 males) enrolled in grades four and five in one senior elementary school in the Greater Montreal Area. All were considered at-risk for reading difficulties based on standardized assessments conducted as part of larger study investigating the relationship between reading and math ability among students in grades four and five. The criteria for selection were as follows: (a) students scored below 25th percentile words correct per minute in Fall DIBELS ORF (Hasbrouck & Tindal, 2017), (b) student scored below grade level in GRADE Total Test (Grade Equivalent), (c) student scored ±1 grade level in Applied...
Problem Solving subtest in KeyMath-3 (Grade Equivalent). The demographic information and relevant test scores are displayed in Table 1. All participant names have been changed to ensure confidentiality.

**Table 1. Demographic Information and Diagnostic Test Scores of Participants.**

<table>
<thead>
<tr>
<th>Participant</th>
<th>Gender</th>
<th>Age</th>
<th># of weeks</th>
<th>Grade</th>
<th>GRADE</th>
<th>WCPM</th>
<th>KeyMath APS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Esther</td>
<td>F</td>
<td>9.1</td>
<td>4</td>
<td>4</td>
<td>2.5</td>
<td>66</td>
<td>6.3</td>
</tr>
<tr>
<td>Anna</td>
<td>F</td>
<td>9.9</td>
<td>5</td>
<td>4</td>
<td>2.4</td>
<td>47</td>
<td>3.9</td>
</tr>
<tr>
<td>Kenny</td>
<td>M</td>
<td>10.1</td>
<td>6</td>
<td>4</td>
<td>1.8</td>
<td>23</td>
<td>3.3</td>
</tr>
<tr>
<td>Brad</td>
<td>M</td>
<td>10.2</td>
<td>4</td>
<td>5</td>
<td>3.9</td>
<td>145</td>
<td>5.8</td>
</tr>
<tr>
<td>Jamie</td>
<td>M</td>
<td>10.7</td>
<td>5</td>
<td>5</td>
<td>3.5</td>
<td>78</td>
<td>6.4</td>
</tr>
<tr>
<td>Selina</td>
<td>F</td>
<td>11</td>
<td>6</td>
<td>5</td>
<td>2.8</td>
<td>73</td>
<td>4.2</td>
</tr>
</tbody>
</table>

Note. Grade Equivalent scores for GRADE test and KeyMath APS; GRADE = Group Reading and Diagnostic Evaluation; WCPM = Average Words Correct per Minute in Dynamic Indicators of Early Literacy Skills Oral Reading Fluency, 6th Edition; KeyMath APS = Applied Problem Solving subtest, KeyMath-3 (Connolly, 2008)

**Design.** A single case multiple-baseline design across participants was used to examine the effects of a contextually enhanced reading program on word problem solving. The enhanced reading program was implemented sequentially across participants. Results were analyzed using Baseline Corrected Tau method (Tarlow, 2017) for estimating effect sizes in Single Case Experimental Design (SCED) data, in addition to visual and descriptive analyses. The study was conducted in the Spring and Summer of 2020. Each participant was scheduled for sessions via Zoom video. Sessions took place three times a week and lasted for one-hour each. Baseline sessions lasted for 1-3 weeks and were followed by experimental condition for 3 weeks. Sessions were recorded for the entire duration. Digital platforms used for designing the tools used have been described in the previous section. Figure 2 shows the timeline of baseline and experimental sessions. Students started with basic blending and vocabulary exercises and more time was spent on practicing the skills that each student was identified to be struggling with, based on their pre-test scores (Table 1).

**Figure 2. Timeline for Baseline and Treatment Condition Implementation.**

<table>
<thead>
<tr>
<th>Week</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Child 1</td>
<td>Baseline</td>
<td>Vocabulary</td>
<td>Treatment</td>
<td>Context</td>
<td>Comprehension</td>
</tr>
<tr>
<td></td>
<td>3 sessions</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Child 2</td>
<td>Baseline</td>
<td>Vocabulary</td>
<td>Treatment</td>
<td>Context</td>
<td>Comprehension</td>
</tr>
<tr>
<td></td>
<td>6 sessions</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Child 3</td>
<td>Baseline</td>
<td>Vocabulary</td>
<td>Treatment</td>
<td>Context</td>
<td>Comprehension</td>
</tr>
<tr>
<td></td>
<td>9 sessions</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Measures.** The following dependent measures were used during the baseline and intervention sessions.

**Word Problem Solving Probes (WPSP).** The first author developed sets of one- and two-step math word problems for this study. Each probe set consisted of four problems (at least one of each problem type - change, compare, combine). The problem types were included based on the problem categorization developed by Riley et al., (1984). A total of 72 questions were developed for each grade level, with each problem coded for number of steps (1-2), problem length (3-4 sentences), operation used (addition, subtraction), and arithmetic skill (money, quantity, time). Table 2 presents sample problems used in the study along with problem characteristics. One point was awarded for each correct answer in the probe set containing a total of four problems. The percentage of correct word problems, calculated by total points for correct answer in a probe divided by total possible points, was used as a dependent measure.

**Table 2. Sample word problems along with problem characteristics and graphic organizers.**

<table>
<thead>
<tr>
<th>Schema</th>
<th>Problem statement</th>
<th>Graphic Organizer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change</td>
<td>The bakers at the Beverly Hills Bakery baked 200 loaves of bread on Monday morning. They sold 93 loaves in the morning and 39 loaves in the afternoon. How many loaves of bread did they have left?</td>
<td></td>
</tr>
<tr>
<td>Combine</td>
<td>William has a lemonade stand. Today he made $17.50 in lemonade sales and half that amount in cookie sales. How much money did William make altogether?</td>
<td></td>
</tr>
<tr>
<td>Compare</td>
<td>Kevin and Karan went fishing together. Kevin caught 21 bass and 7 salmon. Karan caught 13 bass and 8 salmon. How many more fish did Kevin catch than Karan?</td>
<td></td>
</tr>
</tbody>
</table>

**Applied Problem Solving Subtest.** The Applied Problem Solving subtest of KeyMath-3 Diagnostic Assessment (Connolly, 2008), a norm-referenced mathematics concepts and skills assessment, was administered to the students before and after the intervention. The reported internal reliability for Applications subset is .85. Form A was administered during initial data-collection phase and Form B was administered after interventions. The Applied Problem Solving subtest measures an individual’s ability to interpret problems set in a context and to apply computational skills and conceptual knowledge to produce a solution. The subtest contains 35 items in total.

**Results**

Visual analysis, Percentage of Nonoverlapping Data (PND) (Scruggs et al., 1987), and Baseline Corrected Tau (Tarlow, 2017) methods were used to analyze individual performance across conditions, as well as estimating effect sizes for the intervention.
Visual analysis characteristics include level, trend, variability, overlap of data points, consistency, and immediacy (Ledford et al., 2018). Figures 3 and 4 show the trend and variability in performance on WPSP and KeyMath APS subtest for the grade four and five students respectively.

Figure 3. Visual Analysis for Grade Four Students after Math CORPS Intervention.

Figure 4. Visual Analysis for Grade Five Students after Math CORPS Intervention.

Descriptive statistics and results investigating a functional relation between phases are presented in Table 3. Grade four students started the study with their scores at or below 25 percent correct responses on the WPSP. Grade five students showed greater variability in their performance as compared to grade four students. Four out of six students present a stable treatment condition (>80% data points within stability envelope). An increase in percentage of correct response in KeyMath APS subtest also indicate a significant effect of treatment.

Table 3. Descriptive Data and Visual Analysis Results in Percentages.

<table>
<thead>
<tr>
<th>Participant</th>
<th>n-A</th>
<th>Baseline trend</th>
<th>Baseline Corrected Tau</th>
<th>SE_{tau}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Esther</td>
<td>3</td>
<td>.616</td>
<td>.643*</td>
<td>.313</td>
</tr>
<tr>
<td>Anna</td>
<td>6</td>
<td>.258</td>
<td>.704*</td>
<td>.259</td>
</tr>
<tr>
<td>Kenny</td>
<td>9</td>
<td>.624</td>
<td>.684*</td>
<td>.243</td>
</tr>
<tr>
<td>Brad</td>
<td>3</td>
<td>.816</td>
<td>.674*</td>
<td>.302</td>
</tr>
<tr>
<td>Jamie</td>
<td>6</td>
<td>.501</td>
<td>.690*</td>
<td>.264</td>
</tr>
<tr>
<td>Selina</td>
<td>9</td>
<td>.393</td>
<td>.743*</td>
<td>.223</td>
</tr>
</tbody>
</table>

Note. *significant at \( p < .05 \). n-A = number of baseline phase cases; \( SE_{\text{tau}} \) = Standard Error Tau

Table 4. Descriptive Data and Visual Analysis Results in Percentages

<table>
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<tr>
<th>Participant</th>
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<td>.223</td>
</tr>
</tbody>
</table>

Note. *significant at \( p < .05 \). n-A = number of baseline phase cases; \( SE_{\text{tau}} \) = Standard Error Tau

**Discussion**

The results of this study provide empirical evidence of the effectiveness of a contextually enhanced reading program on WP solving in grades four and five. There was a significant moderate to high increase in performance for all students, with BCT effect sizes for intervention ranging from .643 to .743. Visual Analysis indicated a significant positive trend in treatment phase for four out of six participants.

**Baseline Condition.** Reading fluency deficits were noted for five out of six students in the study. Vocabulary deficits were noted for two students in grade four and one in grade five. All students struggled with overall comprehension. Fluency acts as a bridge between decoding and effective comprehension; comprehension may be significantly impaired due to an inability to recognize words (Clemens et al., 2017). Previous studies have recognized computer-assisted instruction as an effective tool in developing reading fluency (Biancarosa & Griffith, 2013; Yang, Kuo, Ji, & McTigue, 2018). Technology-based tools have played a significant role in reading instruction.
role in enabling differentiated instruction, tracking progress, and encouraging collaborative learning (Lindeblad et al., 2017). It is also seen that technology-enhanced reading instruction predominantly addressed vocabulary and comprehension skills (Yang, Kuo, Ji, & McIntigue, 2018; Hutchison & Colwell, 2015). Results from the current study align with these findings, in that effective technology-enhanced reading interventions should address all three aspects explicitly. Having said that, it was also noted that adapting general language instruction for domain-specific skills such as math word problem solving requires additional efforts. Even as Abrami et al. (2015) presented the effectiveness of ABRACADABRA at applying technology to broaden learning themes, results from the current study indicate that general language comprehension gains may not be enough to retain gains in math WPS.

**Treatment Condition.** The reading intervention has a moderate to high impact on improving WPS in participants in grades four and five, as evidenced by effect sizes calculated using BCT method. Visual Analysis of the data also indicates a stable baseline and low to moderate variability for most participants, with a clear positive trend indicating improvement in WPS performance. These findings are in line with current research, stating the importance of language comprehension, specifically context-based comprehension, in facilitating word problem solving in mathematics (Fuchs et al., 2018; Powell, Berry, & Tran, 2020). Schema-instruction was provided using multiple modalities, with explicit teaching of math-specific vocabulary that was also displayed prominently on student screens. In a recent review by Jamshidifarsani et al. (2019) of 32 technology-based reading programs, interventions targeting vocabulary were found to be massively overlooked. Developing technology-based intervention programs is even more difficult, given the varied challenges inherently associated with math vocabulary (Rubenstein & Thompson, 2002). The Math CORPS program addresses these challenges effectively. Graphic Organizers have also been found to be effective tools for remote learning (Taylor & Hwang, 2021). In Math CORPS program, this was augmented by creating personalized story problems to contextualize understanding. The online platform was helpful in this context as it allowed the students to create new stories in real time and use digital graphic organizers to illustrate the different story parts relevant to the schema. We know that students are more prone to making arithmetic errors when they fail to comprehend what the problem is asking them to do (Adelson et al., 2015). Technology-enhanced intervention programs primarily target comprehension skills, with a wide array evidence for its effectiveness in improving narrative and expository text comprehension (Kendeou et al., 2014; Gustafson et al., 2011). Math CORPS Comprehension module consisted of activities that helped students practice summarizing, predicting, and questioning strategies. Schema-instruction is an efficacious form of WP-specific comprehension (Powell & Fuchs, 2018). In addition, Afferbach et al. (2017) emphasize the importance of explicit teaching and modeling of comprehension strategies like predicting, inferencing, and summarizing in effective strategy instruction.

Results of this study provides an opportunity for teachers and educators to reimagine what it means to “learn to read” and adapting their curriculum to address the needs of a post-pandemic world where remote learning and digital tools may become the norm. Teaching reading cannot be the sole responsibility of the Language Arts instructor. The nuances and strategies for reading in a specific domain should be taught explicitly by instructor in that domain. A Math teacher, Science teacher, and a History teacher can be a reading teacher when provided with an effective and targeted program. In addition, technology use needs to be more intentional and meaningful in its design and implementation. Conceptual models such as Technological Pedagogical and Content Knowledge (TPACK) can provide a framework for unique ways in which to incorporate technology into literacy instruction (Mishra & Koehler, 2006; Voogt & McKenney, 2017).

In conclusion, the results of this study add to the literature investigating the causal relationship between reading comprehension and a context-heavy domain like mathematics. Word problem solving ability involves a complex interaction of arithmetic knowledge, problem-solving, and reading comprehension skills. For students struggling in WP solving, a digital intervention such as Math CORPS Program can provide a means of practicing and implementing domain-specific strategies informed by best practice reading approaches. The Math CORPS Program adds to the teacher’s toolkit of effective technology strategies that address the language aspect of math instruction and supporting effective WP solving. The results warrant a large-scale implementation of the program to track its effectiveness amongst students with varying academic needs.

**References**


