Abstract Title Page

**Title:** Concurrent Difficulty with Reading Comprehension and Mathematics Problem Solving: A Role for Language Comprehension

**Authors/Affiliations:** Donald L. Compton, Lynn S. Fuchs, Douglas Fuchs, Pamela M. Seethaler, and C. Melanie Schuele, Vanderbilt University

**Note:** This research was supported by R24HD075443, R01HD059179, and Core Grant HD15052 from the Eunice Kennedy Shriver National Institute of Child Health & Human Development to Vanderbilt University. The content is solely the responsibility of the authors and does not necessarily represent the official views of the Eunice Kennedy Shriver National Institute of Child Health & Human Development or the National Institutes of Health.
Abstract Body

**Background/Context:** Our conceptual framework was based on Kintsch and colleagues’ seminal work in which mathematics problem solving (MPS) is thought to involve an interaction between (a) language comprehension (LC) processes and (b) problem-solving strategies that rely on working memory (WM) and reasoning (e.g., Cummins et al., 1988; Kintsch & Greeno, 1985; Nathan et al., 1992). The model assumes that general features of the text comprehension process apply across stories, essays, and MPS statements, but the comprehension strategies, the nature of required knowledge structures, and the form of resulting structures, inferences, and problem models differ by task. The model poses that the process of building the propositional text structure, inferencing, identifying schema, and applying solution strategies makes strong demands on WM and reasoning. However, as Kintsch et al. discussed, MPS also relies heavily on LC, whereby children “understand important vocabulary and language constructions prior to school entry” (p. 111) and “through instruction, learn to treat these words in a special, task-specific way” (p. 111). This suggests 2 forms of LC are involved in MPS: general LC, which applies in and out of school and to multiple types of academic competence within school, and MPS-specific language.

**Purpose/Objective/Research Question/Focus of Study:** We considered the effects of 6 cognitive abilities for which the literature indicates a role in arithmetic or MPS: WM (counting recall span and listening span task), reasoning (i.e., non-linguistic concept formation), general LC, and processing speed. We examined the direct effects of these abilities on MPS, but simultaneously considered whether the effects are mediated by 2 types of LC: understanding of language that determines (a) bigger and smaller quantities and (b) whether a problem compares two quantities or describes a change in quantity. In the model testing these effects, we controlled for students’ arithmetic competence. Our hypothesis was that MPS depends on WM, reasoning, and general LC and that the effects of general LC are partially mediated by MPS-specific LC. Also, to create a stringent test of this hypothesis, we tested a parallel model using traditional text comprehension as a second outcome and using word recognition to control for foundational skill. Our second hypothesis was that text comprehension also depends on WM, reasoning, and general LC but that, in contrast to MPS, the effects of general LC on text comprehension are entirely direct (i.e., not mediated by MPS-language).

**Participants:** Participants were 206 children, randomly sampled from second-grade classrooms, stratifying by at-risk status (low vs. average/high mathematics performance at the start of 2nd grade). On the Wide Range Achievement Test (WRAT)-Arithmetic, mean performance was 93.04 (SD = 12.38); on WRAT-Reading, 102.10 (SD = 13.98); on KeyMath-Revised-Problem Solving, 105.92 (SD = 9.29); on Woodcock Reading Mastery Tests-Passage Comprehension (Woodcock, 1998), 100.66 (SD = 10.20); and on Wechsler Abbreviated Scale of Intelligence (Wechsler, 1999), 95.89 (SD = 12.34).

**Research Design:** Concurrent prediction of outcomes focused on examining total, direct, and indirect effects of the foundational academic skill and general cognitive abilities on MPS and on text comprehension.

**Data Collection:** Processing speed. With *WJ-III Visual Matching* (Woodcock, McGrew, & Mather, 2001), children locate and circle two identical numbers in rows of six numbers; they have 3 min to complete 60 rows. As per Woodcock et al., reliability is .91. Central executive working memory. We
administered measures of central executive working memory from the *Working Memory Test Battery for Children* (WMTB-C; Pickering & Gathercole, 2001): Counting Recall and Listening Recall. Each subtest has six items at span levels from 1-6 to 1-9. Passing four items at a level moves the child to the next level. At each span level, the number of items to be remembered increases by one. Failing three items terminates the subtest. We used the trials correct score. For *Listening Recall*, the child determines if a sentence is true; after making true/false determinations for a series of sentences, the child recalls the last word of each sentence. For *Counting Recall*, the child counts a set of 4, 5, 6, or 7 dots on a card; after counting a series of cards, the child recalls the number of counted dots of each card. We considered these measures of the central executive separately, based on prior work showing their predictive value differs, depending on type of mathematics outcome (Fuchs et al., 2010b). Non-linguistic *concept formation*. With *WJ-III Concept Formation* (Woodcock et al., 2001), children identify the rules for concepts when shown pictorial, nonverbal illustrations of instances and non-instances of the concept. Pictures are of different shapes in different sizes and colors. Examinees earn credit by correctly identifying the rule that governs each concept. Cut-off points determine the ceiling. The score is the number of correct responses. As reported by the test developer, reliability is .93 for 8 year olds. LC *Woodcock Diagnostic Reading Battery* (WDRB)-*Listening Comprehension* (Woodcock, 1997) measures the ability to understand sentences or passages. With 38 items, students supply the word missing at the end of sentences or passages that progress from simple verbal analogies and associations to discerning implications. Reliability is .80 at ages 5-18. Arithmetic. From the *Mathematics Assessment Battery* (Fuchs, Hamlett, & Powell, 2003), *Arithmetic Combinations* includes four subtests: Sums to 12 (25 addition problems with sums from 5 to 12); Sums to 18 (25 addition problems with sums from 5 to 18); Minuends to 12 (25 subtraction problems with minuends from 5 to 12); and Minuends to 18 (25 subtraction problems with minuends from 5 to 18). For each subtest, students have 1 min to write answers. We used total number of correct answers across addition and subtraction. Coefficient alpha on this sample was .95. *Word recognition*. With *Word Identification Fluency* (Fuchs, Fuchs, & Compton, 2004), children are presented with a single page of 50 high-frequency words randomly sampled from 100 high-frequency words from the Dolch pre-primer, primer, and first-grade level lists. They have 1 min to read words. If they hesitate on an word for 4 s, the tester prompts them to proceed. If they finish reading in less than 1 min, the score is pro-rated. Test-retest reliability on this sample was .86. MPS-*Specific Language Measures*. The *Word Problem-Specific Language Assessment* (Fuchs, DeSelms, & Deason, 2012) includes two subtests. On each, testers read problems aloud to students, who follow along on an image projected at the front of the class and on their own papers. Students can request re-readings as needed, and they write responses on their papers. The first subtest, *Bigger/Smaller MPS Language*, assesses understanding of MPS-specific language that determines bigger and smaller quantities, with two types of items. The first (eight items) asks students to identify whether the quantity referred to in the question is the bigger number, the smaller number, or the difference between the numbers (e.g., *Linda has 3 toys. She has 8 fewer toys than Jane. How many toys does Jane have?*). The second type (eight items) asks students to identify which of four sentences matches the meaning of a sentence describing a compare relationship (e.g., *Sue has 4 less stickers than Jan*, response options are: *Jan has 4 fewer stickers than Sue; Jan has 4 more stickers than Sue; Sue has 4 more stickers than Jan; None of the above*). All items of the first type were presented before the second type. Across 16 items, coefficient alpha on this sample was .86. The second subtest assesses, *Compare/Change MPS Language*, understanding of MPS-specific language that determines whether a problem compares two quantities or describes a change in quantity for one object. This speaks to potential confusion between compare versus change problems with the MPS-specialized use of *more* in combination with *than* and *then* (e.g., someone having *more than* someone else versus someone having a quantity and *then* getting more). Students identified whether the problem talks about the difference between two amounts or about a starting amount that changes (e.g., *Robin had 4 pieces of candy. Then she went to the store and bought 8 more pieces. How many pieces of candy does she have now?*). The order of compare and change
problems was mixed. Coefficient alpha on this sample was .69. Outcomes. *Word Problems* (Jordan & Hanich, 2000) comprises 14 word problems representing combine, compare, and change word problems, which require simple arithmetic for solution. For combine problems, the missing information can be one of the subsets or the total; for compare problems, the missing information can be one of the amounts to be compared or the difference; and for change problems, the missing information can be the starting, change, or end amount. The tester reads each problem aloud; students have 30 s to write a numeric answer (labels are not required) and can ask for re-reading(s) as needed. The score is the number of correct answers. Coefficient alpha on this sample was .88. The *Passage Comprehension subtest of the Woodcock Reading Mastery Tests-Revised-Normative Update* (Woodcock, 1998) uses a modified cloze (or maze) procedure. For the first set of items, the tester presents a rebus, and the child points to the picture corresponding to it. Next, the child points to the picture representing words printed on the page. On later items, the child reads a sentence or passage silently and identifies the missing word. The items students show evidence of understanding the text’s essential ideas (i.e., the propositional text structure) or the ability to build the situation model (i.e., supplement the text with inferences based on the child’s world knowledge). Split-half reliability is .91. Testers were trained to criterion on each measure and used standard administration directions. In in fall of second grade, testing occurred individually in a quiet room for all tests except Arithmetic, MPS-Specific Language, and Word Problems, which were group administered in classrooms or small groups in a quiet location outside the classroom. Interscorer agreement on group-administered tests exceeded 98%. All individual sessions were audiotaped; 15% of tapes were selected randomly, stratifying by tester, for accuracy checks by an independent scorer. Agreement exceeded 99%. We used the Preacher and Hayes (2008) SPSS mediate macro to obtain estimates, with bootstrapping (5000 draws to estimate standard errors) applied to construct 95% confidence intervals for indirect effects.

**Findings/Results:** In predicting MPS, foundational mathematics skill, in the form of arithmetic, plus 2 general cognitive abilities, reasoning (in the form of concept formation) and general LC, exerted direct effects. Beyond these significant direct effects, concept formation and LC (but not arithmetic) also affected MPS indirectly: concept formation via Bigger/Smaller MPS Language and Word Problems, which were group administered in classrooms or small groups in a quiet location outside the classroom. Split-half reliability is .91. Testers were trained to criterion on each measure and used standard administration directions. In in fall of second grade, testing occurred individually in a quiet room for all tests except Arithmetic, MPS-Specific Language, and Word Problems, which were group administered in classrooms or small groups in a quiet location outside the classroom. Interscorer agreement on group-administered tests exceeded 98%. All individual sessions were audiotaped; 15% of tapes were selected randomly, stratifying by tester, for accuracy checks by an independent scorer. Agreement exceeded 99%. We used the Preacher and Hayes (2008) SPSS mediate macro to obtain estimates, with bootstrapping (5000 draws to estimate standard errors) applied to construct 95% confidence intervals for indirect effects.

**Conclusions:** With respect to the idea that the general features of the text comprehension process apply to MPS, we found that non-linguistic reasoning, LC, and WM supported both outcomes, with many similarities. The direct effects of non-linguistic reasoning and general LC were significant for both outcomes, with respective beta coefficients of .20 and .11 for MPS and .14 and .17 for text comprehension. This was also the case for total effects (direct and indirect effects), with respective coefficients of .25 and .16 for MPS and .15 and .18 for text comprehension. Also, WM appeared involved in supporting both outcomes, again in similar ways. Beta coefficients summed across the 2 span tasks to .17 for MPS and .12 for text comprehension. This brings us to Kintsch and Greeno’s (1985) hypothesis that a second form of LC, MPS-specific LC, applies to MPS but not to other forms of text comprehension. In the present study, we found support for this view. The effects of general LC on text comprehension were entirely direct, but partially mediated by specific MPS language in predicting MPS performance. In these ways, results suggest that a dual focus on LC may represent a productive strategy for early intervention to prevent MPS difficulty. This represents a novel direction in MPS
intervention, which has been dominated by a focus on problem-solving strategies designed to compensate for at-risk children’s weaknesses in reasoning and WM.