Understanding and Promoting First-Grade Mathematics Development:
A Randomized Control Trial

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The purpose of this study was to assess the efficacy of and processes by which
two forms of tutoring contribute to at-risk first graders’ number sense, number
combination skill, and word-problem performance. At the start of first grade, at-risk
students were randomly assigned, at the individual level while blocking within
classroom, to three conditions: (1) control (no tutoring, controlling for maturation and the
classroom mathematics program); (2) number concepts tutoring + practice on the number
concepts underlying number combinations and in solving number combinations; and (3)
the same number concepts tutoring + strategic, timed practice designed to build fluency
with counting strategies. In this abstract, we refer to these study conditions, respectively,
as control, number concepts practice, and fluency/strategy practice. Tutoring in the two
active tutoring conditions occurred 3 times per week for 16 weeks; each session lasted 30
minutes. The nature of the first 25 minutes of tutoring during each session was the same
in both conditions, focusing on number symbols and concepts, including those underlying
number combinations. Only the form of practice, which occurred during the last 5
minutes of each session, differed. We also included a group of not-at-risk classroom
peers for comparison purposes (referred to as not-at-risk).

Before and after tutoring, students were pre- and posttested on number sense,
addition and subtraction number combinations, word problems, and Geary’s Addition
Strategy Assessment (i.e., counting errors and automatic retrieval). Also, before intervention, we collected data on students’ cognitive resources (i.e., central executive working memory, phonological loop, visual spatial sketchpad, nonverbal reasoning, oral language, and attentive behavior). Every tutoring session was audiotaped, and fidelity was coded on 20% of tapes, randomly sampled while stratifying on tutoring condition to represent tutor, student, and session number comparably. The percentage of tutoring components included in sessions was high and not significantly different between tutoring conditions. Each tutor taught similar numbers of students in both tutoring conditions (to minimized effects of tutor quality). Yet, the percentage of tutoring components specifically for the practice segment of tutoring (the only aspect of tutoring that differed across conditions) was high in both conditions, with no significant difference between conditions, indicating contagion did not occur.

To test for treatment effects, we ran a multilevel analysis of covariance for each outcome, accounting for variance associated with classroom instruction. Study condition (not-at-risk vs. control vs. number concepts practice vs. fluency/strategy practice) was the independent variable, and pretest score was the covariate. On number sense and word problems, not-at-risk students improved reliably more than both groups of tutored students, who improved comparably to each other but more than control students. On number combinations, however, fluency/strategy practice students improved reliably more than not-at-risk and number concepts practice students, who improved comparably but more than control students.

We ran parallel models examining the effects of treatment on children’s development of strategic behavior when solving number combinations. Not-at-risk
students decreased counting errors more than both groups of tutored students, who
decreased counting errors comparably and more than controls. On retrieval, not-at-risk
and fluency/strategy practice students improved comparably; both groups of tutored
students improved comparably; and all three of these groups exceeded controls. We also
assessed effects of treatment on number combinations while including strategic
improvement in the model. Results indicated that improvement in both forms of strategic
behavior contributed to number combination development, even as the effects of
treatment on number combination development remained even after controlling for
strategy improvement.

Then we ran a series of multilevel regressions (as with all analyses controlling for
classroom nesting), in which we tested the contribution of students’ incoming cognitive
resources to development, while including the effects of study condition in the models
and testing for interactions between cognitive resources and condition. For number
combination development, significant cognitive predictors were attentive behavior and
central executive working memory, and an interaction occurred between nonverbal
reasoning and condition. Follow-up tests indicated that for the number concepts practice
condition, nonverbal reasoning was associated with development: Students with relative
strength benefitted more from tutoring than students with relative weakness. This was not
the case in other conditions.

For word-problem development, significant predictors were central executive
working memory and nonverbal reasoning, and an interaction occurred between language
and condition and between attentive behavior and condition. Follow-up tests indicated
that for all groups except fluency/strategy practice, stronger oral language ability was
associated with stronger development. For not-at-risk and control students (but not for either group of tutored students), stronger attentive behavior resulted in stronger development. We ran an additional analysis on word-problem development, including the cognitive main effects and interactions as well as number combination outcomes in the model. The goal was to assess whether effects of intervention on word problems occurred simply due to superior number combination performance. Results indicated that although posttest number combination performance contributed to word-problem development, the effects of condition remained significant, as did each of the cognitive main effects and interactions.

In sum, results indicate efficacy for both forms of tutoring, both resulting in stronger number sense, number combinations, word problems, and strategic behavior when solving number combinations, compared to at-risk students who do not receive tutoring. Moreover, number concepts tutoring, when combined with fluency/strategy practice, produced better development of number combinations skill than was the case not only for at-risk students who received number concepts tutoring combined with number concepts practice but also for not-at-risk students. Findings also suggest that effects on number combinations occurred, in part, via more accurate counting as well as automatic retrieval, and effects of tutoring on word-problem development was not simply due to improved number combination skill. Finally, children’s incoming cognitive resources were associated with first-grade mathematics development, with some of those cognitive resources moderating the effects of some forms of instruction. In predicting number combinations development, number concepts tutoring when combined with number concepts practice required stronger nonverbal reasoning for maximizing
response; this was not the case for other study conditions. In predicting word-problem
development, incorporating fluency/strategy practice with number concepts tutoring
reduced the vulnerabilities at-risk students experience in language, and either form of
tutoring reduced the vulnerabilities at-risk students experience in attentive behavior.