Paths to Early Arithmetic:

Informal Calculation and Formal Knowledge of the Number System

Young children show evidence of nonverbal calculation well before they have mastered the conventional symbolic number system. Nonverbal calculation is presumably acquired as part of children's informal experiences and may be based on an underlying quantification system (Butterworth, 1999; Mix, Huttenlocher, & Levine, 2002). The conventional number system, in contrast, is presumably acquired more formally through instruction. To link the two, children must learn how to map the symbols to their informal understandings of quantitative transformations (Mix et al., 2002). In the present research, we used a longitudinal design to examine the relative contribution of these two aspects of early number knowledge to the acquisition of conventional calculation skills.

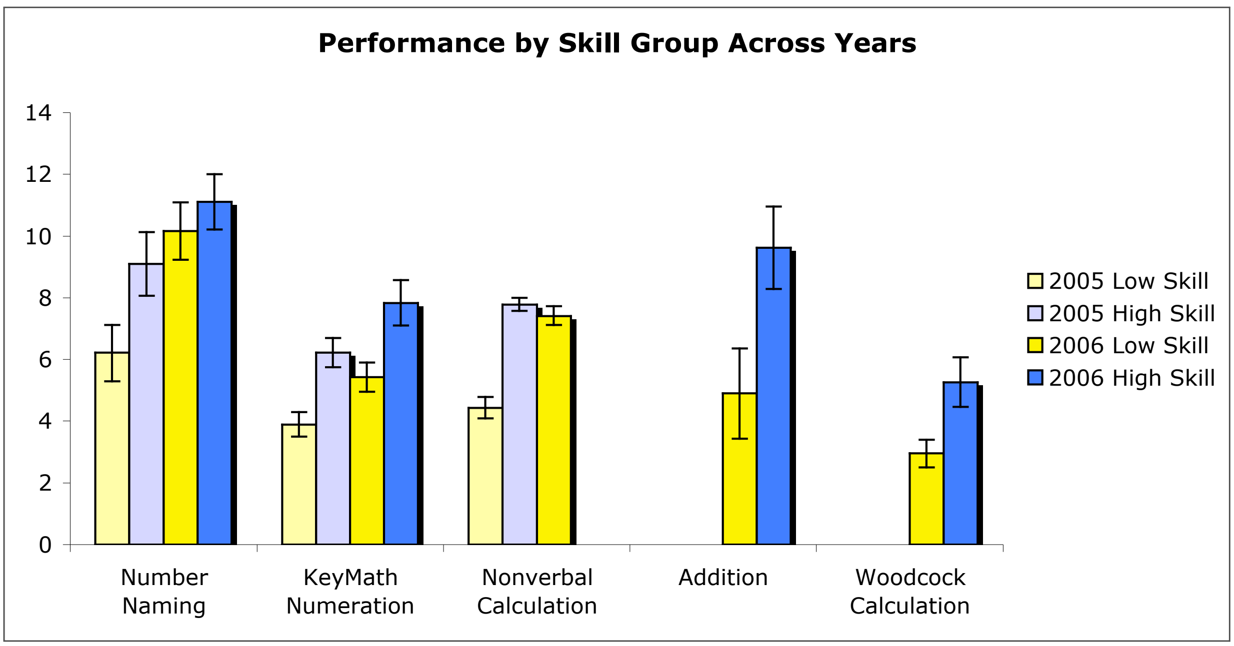
We assessed 38 four-year-old children twice, in the springs of 2005 and 2006. We adapted the nonverbal calculation task used by Huttenlocher et al. (1994). As shown in Table 1, various computer-based and standardized measures were completed each year. Children were classified into skill groups based on their nonverbal calculation performance at age 4.

Table 1. ***Description of Measures***

Category	2005 Measures (age 4)	2006 Measures (age 5)
Nonverbal Calculation	Children watched and modeled toy animals moving in and out of a barn. 9 trials: 3 matching, 3 Addition, 3 Subtraction.	Low Skill group repeated the task. High skill group did not repeat due to ceiling effects.
Symbolic Calculation		Addition Task: 16 trials of sums under 10. Arabic digits displayed on computer (e.g., 1 + 6). Woodcock Johnson-R, Calculation Subtest.
Symbolic Knowledge	Number Naming: child verbally named progressively larger Arabic digits (e.g., 12) displayed on computer. KeyMath Numeration subtest, Form B.	Number Naming: all children repeated in 2006. KeyMath Numeration subtest, Form A.
Receptive Language		Peabody Picture Vocabulary Test, IIIb (PPVT)

Children who made fewer than three errors on the nonverbal task (*n*=19) were deemed high-skill calculators; the other 19 children were deemed low-skill calculators. At age 4, the low-skill calculators also had lower levels of symbolic and conceptual knowledge than the high-skill calculators. As shown in Figure 1, they named fewer Arabic digits $t(36)=-2.10$, $p < .05$ and had lower scores on the KeyMath Numeration subtest, $t(36)=-2.49$, $p < .05$. When the children were retested one year later, the low-skill calculators improved on the nonverbal calculation task. They were also not significantly different than the high-skill group on measures of symbolic knowledge, indicating that they had begun to 'close the gap' for some aspects of numerical skill.

Figure 1. Mean raw score on the measures (+*SE*) by the low and high skill calculator groups at ages 4 and 5.



Despite the gains made on symbolic knowledge, however, comparisons of the calculation skills of the two groups indicated that the poor calculators had not achieved the same gains on measures of calculation: The low-skill children's symbolic calculation skills were still significantly poorer in Kindergarten as measured by number correct on single-digit addition, $t(36) = -2.41$, $p=.021$ and by scores on the Woodcock Calculation subtest, $t(36)=-2.50$, $p=.017$ (see Figure 1). The discrepancies in gains are consistent with the hypothesis that nonverbal representations and conventional number knowledge develop independently.

As another test of the hypothesis that nonverbal and symbolic knowledge develop independently, addition scores and WJ-R calculation scores measured at age 5 were regressed on

nonverbal calculation and number naming performance at age 4, controlling for age, gender, and vocabulary (PPVT). Overall, the model accounted for 53% and 59% of the variance in addition and WJ-R, respectively. As hypothesized, children's Nonverbal Calculation and Number Naming performance at age 4 each contributed significant unique variance to Kindergarten Addition performance (17% and 16%, respectively, for addition; 8% and 18% for WJ-R Calculation). Our findings of these independent pathways have implications for researchers studying predictors of early arithmetic success and for educators helping children acquire calculation skills.