Exploring the Roles of Pattern and Spatial Skills in Early Mathematics Development

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Abstract

Preschoolers' math skills predict later math achievement. While the contribution of number skills to math knowledge is typically studied, early pattern and spatial skills have also been independently shown to predict concurrent and later math knowledge. However, little is known about the relations between pattern and spatial skills, or how both predict math knowledge. Seventy-three 4- to 5-year-olds were assessed at the beginning and end of the preK year. At Time 1, spatial skills repeating pattern skills, and general cognitive skills were assessed. At Times 1 and 2, math knowledge was assessed. Pattern and spatial skills moderately correlated, controlling for age and general cognitive ability. Pattern and spatial skills predicted mathematics knowledge at both T1 and T2. Controlling for T1 math, only pattern skills predicted T2 math knowledge. Thus, curriculum and theory should emphasize the role of pattern and spatial skills in early math development.

Background

- Math knowledge begins to develop at a young age and is predictive of later math and reading achievement (Duncan et al., 2007; Watts et al., 2014). Thus, it is important to determine foundational skills that contribute to this development.
- Two often overlooked skills theorized to contribute to early math development include pattern and spatial skills (Charles, 2005; Sarama & Clements, 2004; Steen, 1988).
- Pattern skills in early childhood predict 5th- and 6th-grade general math achievement, even after controlling for a wide range of other math and cognitive skills, including numeracy knowledge (Nguyen et al., 2016; Rittle-Johnson et al., 2016).
- Multiple studies have also shown a link between spatial skills and later math knowledge, controlling for early math knowledge (Bull et al., 2008; Lachance & Mazzocco, 2006).
- However, the current Common Core Standards (2010) for the early grades give no attention to patterning skills, and minimal attention to spatial skills.

Current Study

The goal of this study was to explore the relations between pattern and spatial skills in preschool-aged children, and how these skills predict concurrent and later math knowledge. We assessed 73 preschool children's repeating pattern skills, spatial skills, general cognitive skills and math knowledge at the beginning of the pre-kindergarten year. We re-assessed their math knowledge near the end of the school year.

Method

***Participants*:**
- 73 students recruited from pre-k classrooms (57.5% female; 46.6% Black, 42.5% Caucasian).
- Mean age when first assessed was 4 years 7 months (*SD* = 4 months)

Pattern Skills (Time 1):
Research-based pattern assessment (Rittle-Johnson et al., 2013; 2015)
Teacher-based pattern assessment (developed by authors using materials from teacher websites)

Spatial Skills (Time 1):
Visual-spatial Working Memory: Corsi Block Tapping Task, Forward and Backward Span on PathSpan program on iPad (Xu & LeFevre, 2016)
Form Perception: Position in Space subtest of the Developmental Test of Visual Perception–2nd edition (Hammill, Pearson, & Voress, 1993)
Spatial Visualization: Block Design subtest of the Wechsler Preschool and Primary Scale of Intelligence–Fourth Edition (Wechsler, 2012)

Math Knowledge (Time 1 and Time 2):
Research-based Early Maths Assessment–Short Form (Clements, Sarama & Liu, 2008)

General Cognitive Skills:
Receptive Vocabulary: The Picture Vocabulary Test from version 1.6 of the *NIH Toolbox* app (Weintraub et al., 2013; Time 1)
Verbal Working Memory: Backward digit span task from the Wechsler Intelligence Scale for Children (Wechsler, 2003; Time 2).

Results

- Pattern and spatial skills strongly correlated (Table 1).
- These skills moderately correlated after controlling for age, verbal ability, and verbal working memory (See Table 1).
- Pattern and spatial skills predicted mathematics knowledge at Time 1 and Time 2, controlling for age, verbal ability, and verbal working memory (See Table 2).
- When also controlling for Time 1 math, only pattern skills significantly predicted Time 2 math knowledge (See Table 2).
- The novel, teacher-based pattern measure was the only consistent unique predictor of math knowledge, controlling for all other skills.

Table 1: Correlations for Key Variables

Variable	*M*	SD	1	2	3	4	5	6	7	8	9	10	11	12
Controls														
1. Age at Time 1	4.5	0.3	---	.33*	.46*	.37*	.41*	.44*	.27*	.27*	.22	.32*	.38*	.46*
2. Verbal Ability	98.0	14.2		---	.42*	.37*	.27*	.36*	.31*	.22	.15	.22*	.39*	.36*
3. Verbal WM	1.5	1.5			---	.52*	.57*	.62*	.54*	.41*	.36*	.55*	.65*	.56*
Target Variables														
4. Research-Pattern	0.1	2.3				---	.56*	.88*	.44*	.48*	.42*	.57*	.57*	.46*
5. Teacher-Pattern	0.0	1.3				.35*	---	.89*	.41*	.40*	.34*	.48*	.64*	.65*
6. *Pattern Composite*	0.0	0.9				.82*	.82*	---	.49*	.50*	.43*	.59*	.69*	.63*
7. Visual-spatial WM	2.6	2.3				.21	.14	.21	---	.51*	.38*	.78*	.50*	.53*
8. Form Perception	6.8	4.6				.33*	.20	.32*	.37*	---	.42*	.82*	.51*	.45*
9. Spatial Visualization	16.0	2.9				.30*	.16	.28*	.24	.31*	---	.77*	.43*	.43*
10. *Spatial Composite*	0.0	0.7				.38*	.23	.37*	.69*	.77*	.74*	---	.61*	.59*
11. Math Time 1	-0.9	0.9				.33*	.42*	.46*	.22	.34*	.28*	.38*	---	.72*
12. Math Time 2	0.1	0.9				.18	.45*	.38*	.32*	.26*	.29*	.40*	.55*	---

Values above diagonal are raw correlations, below are partial correlations controlling for age at Time 1, verbal ability, and WM. *p< .05.

Table 2: Regressions Predicting Math Knowledge

	Math at Time 1			Math at Time 2			Math at Time 2 with Math at Time 1		
Measure	*B*	β	ΔR^2	*B*	β	ΔR^2	*B*	β	ΔR^2
Controls			.44**			.38**			.57**
Age	-.03(.28)	-.01		.52(.30)†	.17		.52(.27)†	.17	
Verbal Ability	.01(.01)	.11		.01(.01)	.10		.00(.01)	.05	
Verbal WM	.16(.07)*	.26		.05(.08)	.07		-.02(.07)	-.04	
Math Knowledge T1	---	---	---	---	---	---	.43(.12)**	.42	
Spatial Skills			.09*			.10**			.03
Visual-Spatial WM	.02(.04)	.05		.08(.04)†	.20		.07(.04)†	.18	
Form Perception	.03(.02)	.14		.01(.02)	.07		.00(.02)	.01	
Spatial Visualization	.03(.03)	.11		.05(.03)	.15		.03(.03)	.11	
Pattern Skills			.07*[a]			.09**[a]			.04*[b]
Research-Pattern	.04(.04)	.10		-.04(.05)	-.09		-.05(.04)	-.13	
Teacher-Pattern	.20(.07)**	.30		.28(.08)**	.40		.19(.07)*	.28	

Note. Beta values represent the final model, ΔR^2 values represent additional variance explained when each set of variables were added to the model. SE's are reported in parentheses. *$p < .05$. **$p < .01$. †$p < .10$. Age is age at time of dependent variable. [a] df = (8, 63). [b] df = (9, 62).

Conclusion

- Pattern and spatial skills are similar but distinct skills in four-year-old children.
- Pattern and spatial skills were unique predictors of math knowledge concurrently as well as 7 months later, over and above the effects of age, verbal ability, and verbal working memory
- Pattern skills helped explain growth in math knowledge over the preschool year.
- The findings highlight the importance of considering the role of pattern and spatial skills in theories of early math development as well as curriculum standards for the early grades.
- Further research is needed on training pattern and spatial skills in order to draw a causal link between these skills and math achievement.