RIT

Language Access, Cognitive Development, and Mathematics Achievement in Deaf and Hard-of-Hearing Learners

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Introduction: Who me?





- Mother, Father Deaf
- Large Deaf family on my mother's side
  - 4 Deaf children out of 9 children in the family
- AAS Educational Interpreting (ASL) RIT/NTID
- BS in Mathematics SUNY Brockport
- MS Interdisciplinary Studies RIT
- Ph.D. University at Buffalo
- American Sign Language Interpreter for 30+ years
- Mathematics Teacher to Deaf students at RIT/NTID for 25 years

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Presentation

- Introduction
  - Background Information on DHH students in mathematics
- How is this study unique?
- What led to these questions?
- Who was included in the study?
- What did I find?
- Discussion

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Introduction

"Math is about a habit of mind. Your mind doesn't think abstractly unless it's asked to -- and it needs to be asked to from a relatively young age. The rigor and logic that goes into math is a good way for your brain to be trained."

("*The Last Time You Used Algebra Was…" By Donald G. McNeil Jr. NYT Dec 12, 2004)*

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The ”Math Gap”

- Math achievement gap: three years, consistent and international (Frostad & Ahlberg, 1999; Phelps & Branyon, 1990; Wood et al., 1983).
- Traxler’s (2000): Stanford Achievement Test 9th Edition DHH students scored in the 'Below Basic’ (Mathematics Procedures) and 'Basic’ (Mathematics Problem Solving)
- At the National Technical Institute for the Deaf (NTID), approximately 50% of DHH students require developmental mathematics courses

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Purpose and Significance of the Study

Identify and clarify key cognitive and linguistic factors

- Verbal Reasoning, Visual-Spatial Reasoning, Relational Reasoning, Linguistic Factors (familial language environment)

Shift in research focus

- **From:** Research related to Basic Numerical Fact and Understanding focused Research

- **To:** Language → Cognition → Mathematical Learning Research

Question: How does language exposure in the home affect the development of the cognitive skills that have been shown to be key factors in mathematical learning and development?

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Language → DHH Development and Outcomes

- The Second International Congress on Education of the Deaf: Milan, Italy, in 1880
- Delayed exposure to a fully accessible language and a lack of qualified mathematics teachers fluent in ASL have cascading adverse effects on DHH students' mathematical development
- DHH children raised in families that use American Sign Language (ASL) often show better language acquisition, emotional development, and general educational outcomes

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Information Deprivation → Cognition → Academic Performance

- Wang, S., Zhou, N., Cao, H., & Lin, X. (2025).
  - Linking deprivation in early childhood with academic performance in middle adolescence through cognitive ability in middle childhood: Nuance by specific cognitive component and heterogeneity by child negative emotionality.
  - Longitudinal Study (n = 2085)
    - Future of Families and Child Well-being Study (n = 2,085)
    - Age 3: Observations
    - Age 9: Cognitive Assessments
    - Age 15: Academic Records
  - No direct effect from age 3 to age 15 (adverse conditions → lower academic achievement)
  - Negative effects from adverse home environments first affect cognitive measures at age 9, which in turn affect academic measures at age 15.

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General Understanding of Math Education DHH Students

- Much of what has been examined points to the unfortunate real-world experience of most DHH children: a world in which inaccessible language stimuli are the norm rather than the exception.
- Despite strides in inclusivity, DHH students still face educational challenges that impact their academic success.
- While research has identified various cognitive and linguistic barriers, a critical gap remains in understanding how environmental factors, such as family language use, interact with cognitive processes to impact mathematical learning.

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Deafness and Informal Math Knowledge

Nunes and Moreno (1998) Informal Mathematical understanding prior to formal schooling.

additive composition, additive reasoning, multiplicative reasoning, ratios, and fractions.

Slower reaction times in tests of basic numerical and arithmetic skills; graphs illustrated similar developmental trends.

Intervention Study: outperformed their previously measured predicted mathematical achievement level (Nunes & Moreno, 2002).

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Visual Spatial Skills: TH peers outperform DHH

Visual-Spatial Task/Skill	Key Research Finding
PMA Spatial Relations Test	Hearing students consistently score higher in **identifying parts that form a complete target shape.**
Minnesota Paper Form Board	Hearing individuals excel at **part-whole relationship skills and assembling component parts into a whole.**
Schematic Representations	Hearing students are **more likely to encode abstract spatial relations** when solving math problems.

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Visual Spatial Skills Tests: DHH peers outperform TH

Visual-Spatial Task/Skill	Key Research Finding
Peripheral Visual Attention	Deaf signers demonstrate heightened perception and enhanced attention to the visual periphery.
Mental Image Generation and Rotation	Sign language expertise is linked to **faster generation and rotation of complex mental images.**
Early Spatial Math (Age 3–4)	Very young Deaf children outperform hearing peers in **spatial numerical tasks and block array recall.**

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Understanding Relationships and Math Ability

- Compact Oxford English Dictionary, Second Edition (2000), defines mathematics as “the abstract science which investigates the conclusions implicit in the elementary concepts of spatial and numerical relations deductively” (p. 1048).
- ***Deaf individuals underperformed their hearing counterparts on tasks that required the consideration of two or more dimensions (Ottem, 1980).***
- ***Deaf and hearing college students solving 4- and 5-term series problems performed comparably when they created external models to show relationships in the 4-term problems (Marschark & Johnson-Laird, 2003).***

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Relational Reasoning in Math

- Relational skills are linked to solving math word problems (Lee et al., 2018; Miller et al., 2014).
- Miller Singley and Bunge (2014) state that **relational reasoning is a crucial foundational skill for learning mathematics.**
- Lee, Swee, and Bull (2018) found that **relational skill predicted students' future algebraic performance** even when controlling for all other variables.

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Fluid Reasoning

- Fluid reasoning: the **ability to analyze novel problems**, **identify patterns and relationships** within them, and **use logic to derive a solution** (Schneider & McGrew, 2012).
- **Fluid reasoning develops in parallel with mathematical skills** between the ages of 5 and 10 (Ferrar & McArdle, 2004).
- **Fluid reasoning is a stronger predictor** of mathematical performance **than verbal ability, numerical reasoning, and spatial skills** (Green et al., 2017).

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Vygotsky's Sociocultural Theory

- Language is a central mediator in learning, providing the foundation for internalizing mathematical concepts (Vygotsky, 1978).
- For DHH learners, early exposure to accessible language facilitates the development of relational reasoning and fluid reasoning (Hall et al., 2019; Lee et al., 2018).
- In ASL-limited environments, cognitive and mathematical development can be significantly delayed (Ansell & Pagliaro, 2006).

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Bronfenbrenner's Ecological Systems Theory

- **Microsystem:** immediate environments, such as family and school
- **Mesosystem:** interactions between environments, such as home and school
- **Exosystem:** broader influences, such as educational policies
- **Macrosystem:** societal attitudes toward disability and language accessibility
- **CHRONOSYSTEM: THE IMPORTANCE OF TIMING**

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The Socio-Cognitive Ecosystem of DHH Learning



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Participants

- Consortium of DHH educational programs
- 778 DHH students from K-12
- 2008 and 2018.
- 195 cases had data related to the independent variables, 75 of those students were enrolled in one of the schools for 9th grade.
- The study examined 75 Deaf and Hard-of-Hearing (D/HH) children (age M = 14.53, SD = 1.1)
- 28 DHH children from homes that self report having at least one parent who learned to sign, 47 DHH without ASL in the home

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Measures

- Intelligence subtests from the Wechsler Intelligence Scale for Children (WISC-IV & WISC-V)
- Measures of Academic Progress (MAP) Mathematics RIT score
- Self-reported parental use of American Sign Language (ASL)

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Intelligence Subtests (WISC)

- **Similarities:** assesses verbal abstract reasoning and verbal concept formation
- **Vocabulary:** evaluates verbal fluency, word knowledge, and concept formation
- **Picture Concepts:** measures categorical, abstract reasoning
- **Matrix Reasoning:** measures visual processing and abstract and spatial perception
- **Block Design:** measures spatial reasoning

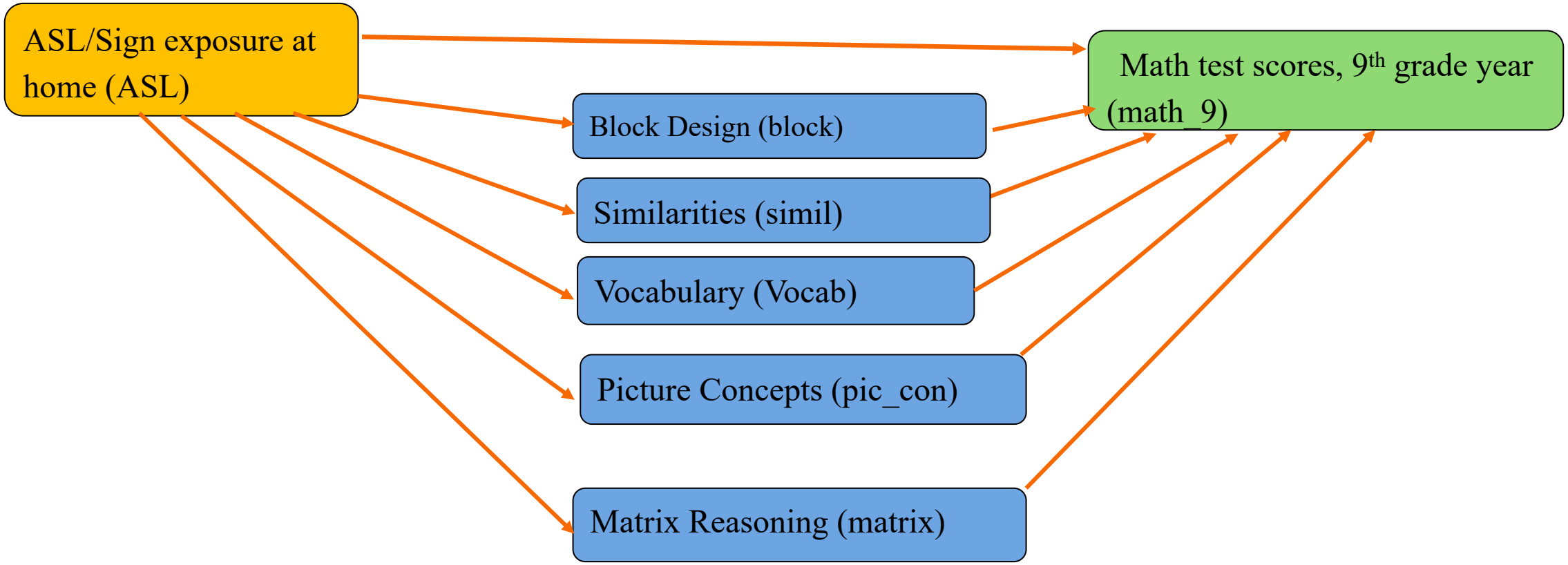
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MAP Mathematics RIT Score

- The MAP Mathematics RIT score provided a standardized assessment of academic performance in math.
- This computer-adaptive test measures students' proficiency across mathematical domains, including number operations, algebraic thinking, and geometry.
- This study analyzed math RIT scores from MAP tests completed during students' 9th-grade year.

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Structural Equation Model



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Pearson Correlations (Overall Sample n = 75)

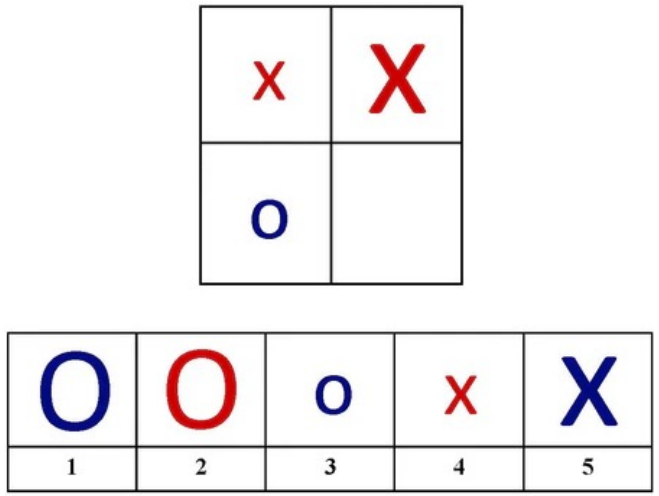
	math_9	ASL	simil	vocab	block	pic_com	matrix
math_9	1.000						
ASL	.631***	1.000					
simil	.612***	.485***	1.000				
vocab	.687***	.558***	.782***	1.000			
block	.478***	.265*	.238*	.291**	1.000		
pic_con	.553***	.430***	.466***	.312**	.338**	1.000	
matrix	.398**	.265*	.360**	.299**	.540***	.581***	1.000

- Pearson correlations between study variables (Deaf children with and without ASL exposure in the home n = 75)
- *Note:* p < .05*, p < .01**, p < .001***

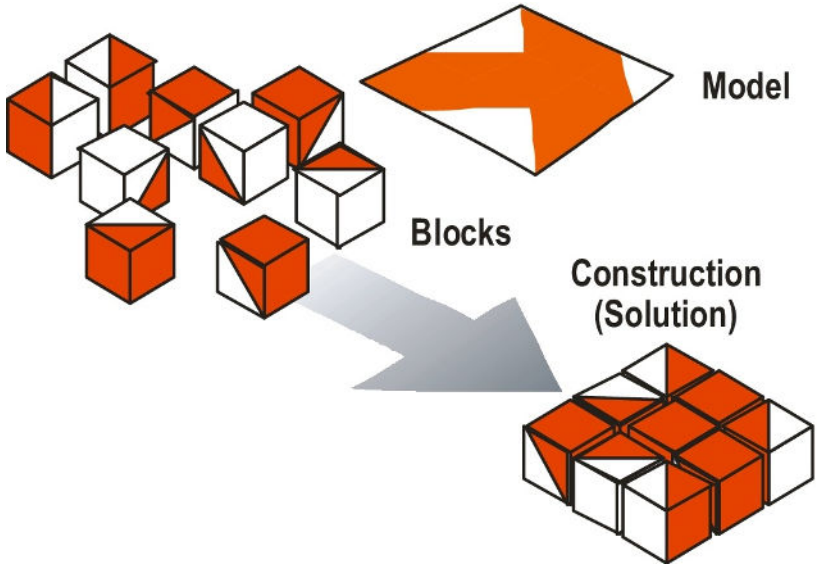
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Language → Non-Verbal Visual – Spatial Relational Skills

Example item from the Matrix Reasoning subtest



Block Design Test



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Regression (n = 75)

$\Delta R^2 = .667$

Model 1	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	149.226	6.576		22.694	<.001
ASL	10.663	4.183	.227	2.542	.011
simil	.175	.882	.026	.199	.843
Vocab	11.892	3.762	.406	3.156	.002
block	1.945	.706	.247	2.754	.006
pic_con	2.065	.670	.286	2.952	.003
matrix	-.722	.782	-.046	-.923	.655

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Regression Beta Weights (n = 27)

$$\Delta R^2 = .587$$

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	149.412	15.538		9.616	<.001
simil	-.810	1.291	-.085	-.627	.531
Vocab	15.242	5.584	.662	2.729	.006
block	2.867	1.128	.397	2.543	.011
pic_con	1.802	1.362	.278	1.323	.187
matrix	-.365	1.226	-.057	-.298	.766

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Regression Beta Weights (n = 48)

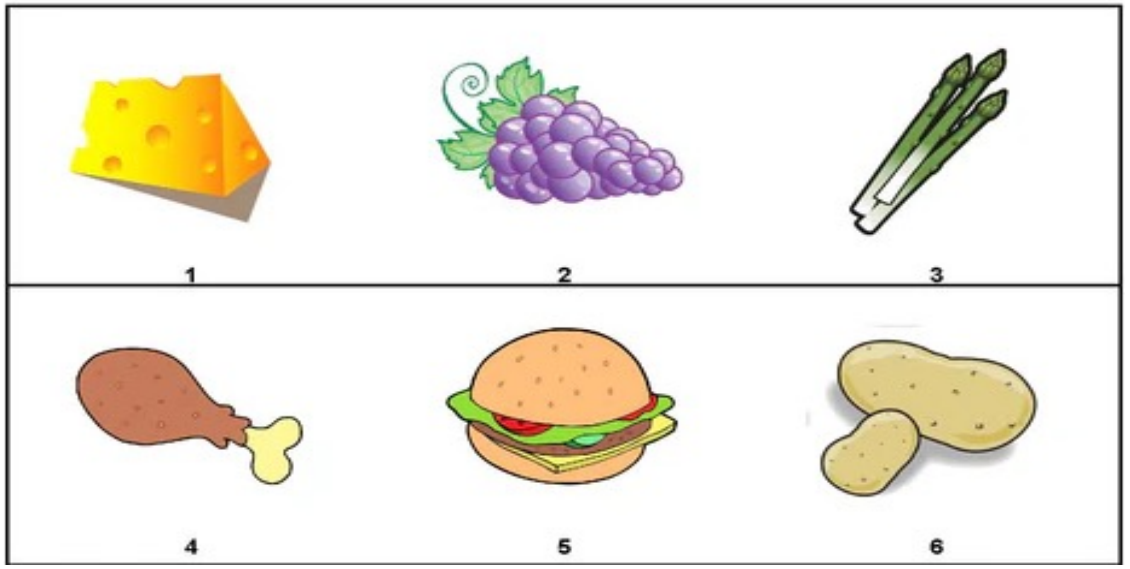
$\Delta R^2 = .439$

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	154.006	8.137		18.927	<.001
simil	1.245	1.192	.187	1.045	.297
Vocab	7.736	5.723	.233	1.352	.179
block	1.507	.979	.259	1.540	.125
pic_com	2.238	.871	.785	2.568	.012
matrix	-.998	1.140	-.161	-.875	.382

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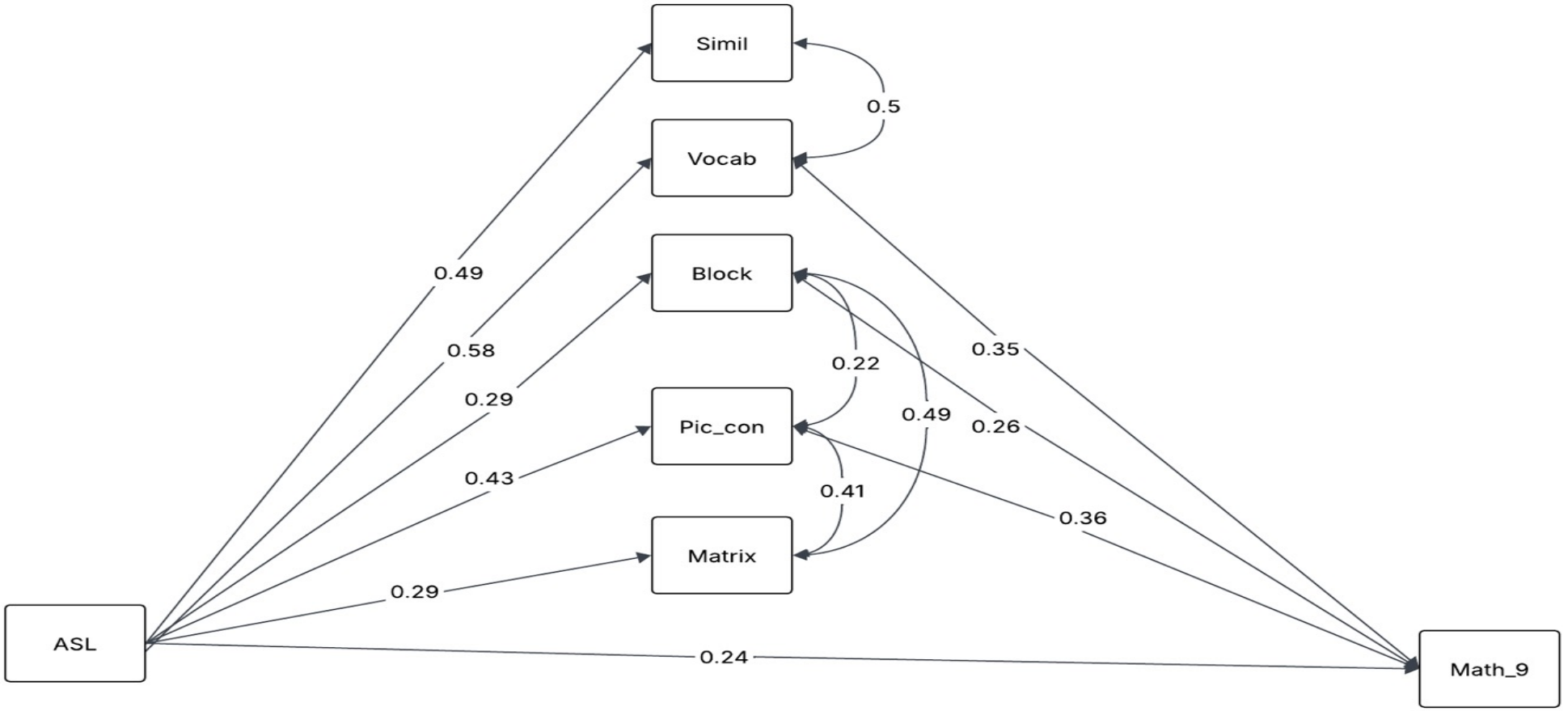
D/HH with no ASL at home, only one predictor?

- Figure 3 Example item from the Picture Concepts subtest



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SEM Model Direct and Indirect Effects of ASL on Math



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Discussion…

- This study examined the relationships between **cognitive abilities**, **home language environments**, and **math achievement** among DHH learners.
- The findings provide critical insights into how **verbal, visual-spatial, and relational reasoning**, along with **environmental factors**, influence academic outcomes in DHH learners.
- **Verbal reasoning** (Vocabulary), **visual-spatial reasoning** (Block Design), and **abstract categorical reasoning** (Picture Concepts) were significant predictors of math achievement for the overall sample.

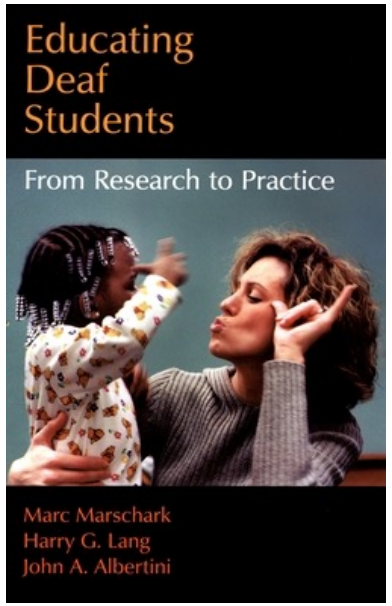
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Implications for Educators

- For students without ASL exposure, interventions should prioritize visual-spatial reasoning using manipulatives, diagrams, and hands-on activities.
- Early intervention programs that promote ASL use at home and in educational settings are critical for mitigating language deprivation and supporting cognitive development.
- **Mathematics is closer to language and cognitive development than a collection of facts and skills** that people need to learn to be successful in math

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Conclusions

- The findings from this study reaffirm the need to embrace this paradigm shift by focusing on the distinctive ways DHH learners process information and develop reasoning skills.
- By identifying and leveraging their strengths while addressing challenges such as language deprivation and limited access to accessible instructional strategies, we can create equitable educational opportunities that empower DHH students to reach their full potential.
- Mathematics is a foundational area of understanding that impacts cognitive growth and overall academic outcomes

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