#### Number Symbols in the Brain & Mind

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# How important are numerical skills?

- Low numeracy associated with unemployment, physical illness, depression & incarceration (Bynner & Parsons 2005)
- Improvements in mathematical competence are related to economic growth (OECD, 2010)
- Health Numeracy: Ability of patients & health professionals to use healthcare information (Golbeck et al., 2005)

## How do numerical skills develop?







### **Foundational Competencies**



#### Matthew Effects in Reading

## Foundational Competencies

Achievement





## A brain system for non-symbolic number



Libertus & Brannon (2009)





How are innate (ANS) and acquired (symbolic) systems related?



#### How do culture and biology interact?







#### Probing Developmental Dynamics

#### Longitudinal approach necessary

Repeatedly test the same children using the same methods

Allow for estimation of direction of relationship



#### **Probing Developmental Dynamics**

lan Lyons

531 children in senior kindergarten (mean age: 5 years and 2 months)

From 35 Schools in the Toronto District School Board

Tested in the fall (September/October) and spring (April/May)

Paper and pencil measures

Lyons et al. (2018), Developmental Psychology



Lyons et al. (2018), Developmental Psychology





Lyons et al. (2018), Developmental Psychology



© 2021 American Psychological Association ISSN: 0012-1649 Developmental Psychology

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Kindergarteners' Symbolic Number Abilities Predict Nonsymbolic Number Abilities and Math Achievement in Grade 1



Added in additional time point: end of Grade 1



- Random intercept cross-lagged model
  - Better distinguish between within-subject vs. between-subject change

Lau et. al. (2021), Developmental Psychology



# What developmental dynamics best fit the data?

#### Contrasting possible developmental models



### Contrasting possible developmental models



### Contrasting possible developmental models



#### Contrasting possible developmental models Refinement Model



Time

Lau et al. (2021), Developmental Psychology

# Change in developmental dynamics? 8 2 **Developmental Time**

# Directionality in the interrelations between approximate number, verbal number, and mathematics in preschool-aged children

Yi Mou<sup>1</sup> | Bo Zhang<sup>2,3</sup> | Daniel C. Hyde<sup>3</sup>

- 2.9-4.3 year olds
- 1-year longitudinal study 3 time points
- Verbal number knowledge, general cognitive abilities, dot comparison (ANS precision)

CHILD DEVELOPMENT

# Directionality in the interrelations between approximate number, verbal number, and mathematics in preschool-aged children



## Developmental Dynamics

- Symbolic number knowledge influences non-symbolic number *from an early age*
- Symbolic number knowledge as an attentional filter?
- Symbolic number changes perception of and focus on nonsymbolic set?



#### Cognition 181 (2018) 35-45



Original Articles

#### Learning to focus on number

Manuela Piazza<sup>a,b,c,\*</sup>, Vito De Feo<sup>d</sup>, Stefano Panzeri<sup>d</sup>, Stanislas Dehaene<sup>a,b,e</sup>

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# A small experiment



#### A small experiment

#### You will see dot arrays

Say as quickly as you can how many dots you see!













# What did you notice?
#### Research Article Does Subitizing Reflect Numerical Estimation?

Susannah K. Revkin,<sup>1,2,3</sup> Manuela Piazza,<sup>1,2,3,4</sup> Véronique Izard,<sup>1,2,3,5</sup> Laurent Cohen,<sup>1,2,3,6,7</sup> and Stanislas Dehaene<sup>1,2,3,8</sup>

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## Different nonsymbolic number processing systems

 There are <u>two</u> distinct systems for non-symbolic number processing

1.**The ANS** – large numbers, approximate processing, estimation

2. Subitizing/Object File System – small numbers, exact enumeration

## Differential developmental dynamics?



## **Differential developmental dynamics?**



Large

- 540 children
- 4.6 5.7 years old
- Fall and Spring of Kindergarten









Hutchison et al (2019), Developmental Science





## Cross-sectional results



# Longitudinal results

Hutchison et al (2019),
Developmental Science



Hutchison et al (2019), Developmental Science

## Differential developmental dynamics?



884 + nov

## **Translating to**

## education



## NUMERACY SCREENER

HOME ABOUT THE TEST GET YOUR SCORE

USERS ABOUT US





Does the numeracy screener predict math scores?



## Symbolic counts!

Outcome: Math grade					
Predictors	β	t	р	$\Delta R^2$	Bayes Factor
Age	.11	1.32	.190	.10	.49
Gender	07	87	.386	.00	.31
Sentence Recall	.23	2.69	.008	.15	18.53*
Rapid Color Naming	02	18	.857	.05	.24
Arithmetic	.05	.58	.562	.01	.31
Number Line (PAE)	13	-1.69	.095	.02	.76
Non-symbolic Comparison	.01	.08	.936	.03	.21
Symbolic Comparison	.38	3.34	.001	.06	649.43***
$*BF_{10} = 3-20, **BF_{10} = 20-150, ***BF_{10} > 150$					

## Is the Numeracy Screener a useful tool for educators?



#### **Exploring the Implementation** of Early Math Assessments in Kindergarten Classrooms: 47% **A Research-Practice** Collaboration 29% Jennifer A. McDonald<sup>1</sup>, Rebecca Merkley<sup>2</sup>, Jacqueline M<sup>2</sup> Hawes<sup>3</sup>, and Daniel Ansari<sup>4</sup> MIND 12% 12% BRAIN. AND 0% EDUCATION Numeracy Screener the gennese on the sourt individual differences Gaund Editor Floor Grinsreeks his you Berges □ Not at all useful □ Slightly useful Moderately useful Very useful

Extremely useful







#### 6 Continents, 13 Countries, 16 regions, 18 datasets





## Data from Ghana

Sharon Wolf

372 Children

7-9 years old

Early Grade Math Assessment (EGMA)

Numeracy Screener (Symbolic & Non-symbolic)







Sharon Wolf

- Multiple regression:
  - Non-symbolic a significant predictor of math scores
  - Symbolic not
- Finding runs contrary to data from Western Countries (e.g. Hawes et al. 2019)
- Set out to replicate in Ivory Coast



## **Data from Ivory Coast**

Sharon Wolf

#### 355 Children

7-9 years old

Early Grade Math Assessment (EGMA)

Numeracy Screener (Symbolic & Non-symbolic)



Multiple regression revealed *non-symbolic* **but not** symbolic as unique predictor of math scores

#### **Developmental Science**

Developmental Science (2016), pp 1-16

DOI: 10.1111/desc.12372

PAPER

Associations of non-symbolic and symbolic numerical magnitude processing with mathematical competence: a meta-analysis

Michael Schneider,<sup>1</sup> Kassandra Beeres,<sup>1</sup> Leyla Coban,<sup>1</sup> Simon Merz,<sup>1</sup> S. Susan Schmidt,<sup>1</sup> Johannes Stricker<sup>1</sup> and Bert De Smedt<sup>2</sup>

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2. Faculty of Psychology and Educational Sciences, Parenting and Special Education Research Group, KU Leuven, University of Leuven, Belgium





r=.24

## The importance of context

Data from.

e contrary to data from Western Samples

How number knowledge is acquired differs across context

Need to take context into account

\*

Go beyond White, Educated, Industrialized, Rich and Democratic (WEIRD) populations

## Insights from Cognitive Neuroscience







(e.g. Bugden et al., 2015; Matejko & Ansari (2022)



CrossMark

Common and distinct brain regions in both parietal and frontal cortex support symbolic and nonsymbolic number processing in humans: A functional neuroimaging meta-analysis

H. Moriah Sokolowski<sup>a</sup>, Wim Fias<sup>b</sup>, Ahmad Mousa<sup>a</sup>, Daniel Ansari<sup>a,\*</sup>



# How differently are symbolic & non-symbolic represented in the brain within participants?



Sokolowski et al. (2021) Cerebral Cortex Communications







## Parallel adaptation Deviants









Zack Hawes



А

X = -45

Y = -65

R

R



Moriah Sokolowski

Symbolic Distance Effect S4 > S1

**Nonsymbolic Distance Effect** N4 > N1

**Physical Size Distance Effect** P4 > P1



Z = 26



Sokolowski et al. (2021) Cerebral Cortex Communications
Cultural/symbolic number development influences preexisting non-symbolic number processing

Differs as a function of set size

Individual differences in symbolic & non-symbolic predict math scores

Relationship strongest for symbolic in Western Samples

Relationship strongest for non-symbolic in West African samples

**Context matters** 

## Summary and conclusion

