When Worlds Unite: Role of Social Interactions in Children’s Mathematical Development

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Background

• Math performance at school entry predicts poor performance in later schooling (Duncan et al., 2007)

• Poor math achievement is linked to lower rate of full-time employment, more frequent rates of unemployment, and lower annual incomes (Geary, 2011)

• Research on math achievement has consistently shown performance gaps for low-SES children (Murphy, 2010; Starkey et al., 2008)
Better Early than Late

“Early interventions targeted toward disadvantaged children have much higher returns than later interventions such as reduced pupil-teacher ratios, public job training, convict rehabilitation programs, tuition subsidies, or expenditure on police.”

-James J. Heckman, Nobel Prize-Winning Economist from the University of Chicago

Outline of Talk

- Integrated Theory of Numerical Development
- Sociocultural Perspective on the Development of Numerical Knowledge
- When Worlds Unite: Games to Improve Early Numerical Knowledge
  - Linear Number Board Games
  - Number Board Games on Tablet Computers
  - Number Card Games
Integrated Theory of Numerical Development

• Numerical magnitude understanding is linked broadly to math achievement (DeSmedt et al., 2013; Fazio et al., 2014)

• Numerical development across the lifespan follows patterns of increasing understanding of numerical magnitudes (Siegler, Thompson, & Schneider, 2011; Siegler, 2016)
  - Non-symbolic magnitudes
  - Non-symbolic magnitudes to symbolic representations
  - Larger whole numbers
  - All rational numbers

Numerical Magnitude Knowledge

Where does 72 go on the number line? (Siegler & Opfer, 2003)

“Who has more?” (Halberda et al., 2008)

“Which is more?“ (Ramani & Siegler, 2008)

8  9
Sociocultural Perspectives on the Development of Numerical Knowledge

• Everyday, informal learning activities can provide children with extensive numerical information (Saxe, 2004).

• Engaging in a variety of playful and informal number activities can influence children’s numerical knowledge (Huntsinger et al., 2000; Skwarchuk, 2009)

• Adults can scaffold children during number activities to guide and assist in their number learning

Combining Theoretical Frameworks

• Integrated Theory of Numerical Development is grounded in an information processing approach
  • Providing theoretically driven information about numerical magnitudes to young children should promote their numerical development

• Drawing on sociocultural theories of development:
  • Providing that information via everyday experiences with adults and peers, such as playing games

• Many early childhood curricula draw from the combination of these frameworks to teach children foundational skills through playful activities (e.g., Building Blocks)
The Power of Play: Linear Number Board Game

- Playing a linear number board game one-on-one with an experimenter promotes the numerical knowledge of Head Start children (Siegler & Ramani, 2008)

- These benefits remain stable over at least a 9-week period (Ramani & Siegler, 2008)

- Improves learning of arithmetic problems (Siegler & Ramani, 2009)

- Improves younger middle-income children’s numerical knowledge (Ramani & Siegler, 2011)

Taking it to the Classroom

- We examined whether playing a number board game in a small group supervised by a teacher’s assistant can improve children’s numerical knowledge.

- We also observed whether the teacher’s scaffolding during the games relate to children’s learning outcomes.

(Ramani, Siegler, & Hitti, 2012, JEP)
Methods

Participants:
• 105 3- to 5-year-old children from Head Start programs
  • M = 4 years 5 months
  • 52% Hispanic; 42% African-American; 6% Other

• 7 teacher’s assistants (paraprofessionals)
  • 6 African-American and 1 Hispanic
  • Average years teaching = 8 years
  • Average years in current classroom = 5 years

• One hour paraprofessional training session prior to study

Methods

Procedure: Six 20- to 25-minute sessions over 4 weeks

Board Game in Small Group: Sessions 2 through 5
• Number Board Game
• Color Board Game

Pretest and Posttest (Session 1 and 6)
• 0-10 Number Line Estimation (Percent Absolute Error)
• 1-9 Numerical Magnitude Comparison
• 1-10 Counting
• 1-10 Numeral Identification

Peabody Picture Vocabulary Test – 4th Edition (PPVT)
Small Group Board Game Play Supervised by Paraprofessional

Results

Number Line Task

- PAE
  - Pretest
  - Posttest

Numerical Magnitude Comparison

- % Correct
  - Pretest
  - Posttest

- Number Board Game
- Color Board Game

*** p < .001; * p < .05
Results

Numeral Identification

Counting

** p < .01

Percentage of Turns With Modeling Assistance

Results – Paraprofessional Assistance
Relations between Assistance and Children’s Numerical Knowledge

<table>
<thead>
<tr>
<th></th>
<th>Number Board Game</th>
<th>Color Board Game</th>
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<tbody>
<tr>
<td></td>
<td>Pretest Number Knowledge</td>
<td>Posttest Number Knowledge</td>
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<td>.12</td>
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<td>-.39**</td>
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<td>.46***</td>
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<tr>
<td>Instruction/Model</td>
<td>-.62***</td>
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</table>

Summary

- Playing a number board game in a small group benefits low-income children
- Number board games can be implemented by teachers in Head Start classrooms with only a brief training
- Paraprofessionals adjusted their feedback in response to the game the children were playing, the session in which the game was being played, and the children’s numerical knowledge.
Current Extensions of Board Game Research

Informal Numerical Activities Played Outside of School (Ramani & Siegler, 2008)

Technology and Education

- Computer games targeting children’s mathematical skills have been successful (Rasanen et al., 2009; Wilson et al., 2009)

- Technological tools, such as tablet computers, have considerable educational potential (Leoni, 2010)
  - Portable
  - Affordable
  - Intuitive
  - User friendly, even for small children

- Despite the numerous apps for mathematics, few are theoretically grounded or tested (Hirsh-Pasek et al., 2015)
Study Aims

• We adapted a 0-100 number board game into a tablet computer game (Laski & Siegler, 2014)

• We also tested the benefits of training activities targeted towards children’s improving children’s underlying cognitive system, specifically, their working memory (WM) skills (Jaeggi et al., 2013).

(Ramani, Jaeggi, Daubert, & Buschkuehl, revise and resubmit)

Domain-specific and Domain-general Training

• According to Geary and Hoard’s framework (2005), difficulties in mathematical achievement may be due to:
  • domain-specific conceptual and procedural numerical knowledge
  • domain-general underlying cognitive systems, such as working memory, which allows temporary storage and manipulation of a limited amount of information during a cognitive task (Shah & Miyake, 1999).

Fig. 1. Conceptual framework adapted from Geary & Hoard (2005).
Domain-Specific Knowledge and Domain-General Skills

- Domain-Specific Knowledge: Numerical magnitude knowledge

- Tasks that assess children’s numerical magnitude knowledge, such as the number line estimation task, require domain-general processing skills (Kolkman, Hoijtink, Kroesbergen, & Leseman, 2013).

- Working memory is critical for children’s procedural knowledge and execution of the strategies used for solving arithmetic problems (Rittle-Johnson & Alibali, 1999).

Methods

Participants

- 81 Kindergarteners recruited from public schools that serves predominately low-income families
  - $M = 6$ years 0 months

- Fourteen 15-minute sessions conducted within 6 week period in the children’s schools

Children randomly assigned to 3 conditions:

- Domain-specific training
- Domain-general training
- No-contact control
Pretest and Posttest Measures

Math tasks

Number Line: Place numbers on a 0-100 number line. (“Where does x go on the number line?”)

Number ID: Label symbolic numbers. (“What number is this?”)

Arithmetic: Add numbers with a sum no greater than 9. (“What is 4 + 2?”)

Working memory tasks

Following Instructions: Follow increasingly complicated directions. (“Put the red pencil in the blue folder.”)

Forward and Backward Digit Span: Repeat series of numbers forward or backward. (“List the numbers I say forward/backward.”)

Results: Math Outcome Measures

![Math Outcome Measures](image)

- Number line
- Number identification
- Arithmetic

Effect Size (Cohen’s d)

Control Group

WM Training

Math Training

*p < .05
Results: Working Memory Measures

Summary and Discussion

- Both the domain-specific and domain-general intervention significantly improved children’s performance in number line estimation

- Using tablet computer games can provide a way to train both areas for young children

- There were significant improvements in working memory in both intervention groups, however, those improvements were restricted to the backward digit span
  → Working memory tasks were very language heavy, and many children struggled with understanding the instructions, resulting in very low and unreliable performance
Card Games to Improve Numerical Knowledge
Integrated Theory of Numerical Development

• For preschoolers, the focus is on:
  • Solidifying symbolic (whole) number representations
  • Linking symbolic to non-symbolic representations

• The process of “linking” of non-symbolic and symbolic representations is not well-understood
  • Symbolic number representations may be built from non-symbolic number representations present in infancy (Brannon, 2006; Dehaene, 2007)
  • Skills may be separate for young children, but become integrated over time and experience (Kolkman et al., 2013)

Magnitude Comparison and SES

• Early SES-related gaps on preschoolers’ symbolic magnitude comparison measures (Jordan et al., 2006; Ramani & Siegler, 2011)

• There may not be gaps on non-symbolic magnitude comparison measures (Jordan et al. 1992; Jordan et al., 1994)
Magnitude Comparison and SES

- **Participants**
  - 23 Head Start preschoolers ($M_{age} = 4$ years, 8 months)
  - 23 mid-income preschoolers ($M_{age} = 4$ years, 9 months)

- **Two measures of magnitude comparison**
  - Non-symbolic Magnitude Comparison
    - Panamath: 20 pairs, quantities ranged from 1-9;
  - Symbolic Magnitude Comparison
    - 20 pairs of symbolic numbers ranging from 1-9 (Ramani & Siegler, 2008).

Non-symbolic and symbolic magnitude comparison

<table>
<thead>
<tr>
<th>Non-Symbolic Magnitude Comparison</th>
<th>Symbolic Magnitude Comparison</th>
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<tbody>
<tr>
<td>Accuracy</td>
<td>Head Start (pretest)</td>
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<tr>
<td>Head Start</td>
<td>Middle-income</td>
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<tr>
<td>Accuracy</td>
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<td>100%</td>
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Magnitude Comparison and SES

• Is it possible to capitalize on low-income preschoolers’ non-symbolic magnitude comparison skills as a means of promoting their symbolic magnitude comparison skills?

Study Aims

• We examined whether providing Head Start children play-based, targeted practice on numerical magnitude comparison is beneficial

• Specifically, we examined whether using cards with both non-symbolic and symbolic number representations can improve early numeracy skills

(Scalise, Ramani, & Daubert, under review)
Methods

• Participants: 46 Head Start preschoolers
  • 3 to 5-years old, $M = 4$ years, 9 months
  • 54% Hispanic/Latino, 35% African American/Black, 7% Asian, 4% Multiracial

• Children played one of two card games for four 15-minute sessions individually with an experimenter using the same cards
  • A numerical magnitude comparison card game (“War”)
  • A numerical memory and matching card game (“Memory”)

Methods:

Pretest and Posttest Measures (Session 1 and 6)
• Rote counting (1 – 10)
• Numeral identification (1 – 10)
• Symbolic magnitude comparison
• Non-symbolic magnitude comparison (Adjusted settings to be more difficult and consistent with previous studies)
Results

Counting

Number Identification

Main effect of session: $p < .05$

Results

Symbolic Magnitude Comparison

Non-symbolic Magnitude Comparison

$** p < .01$
Results

Symbolic Magnitude Comparison

Non-Symbolic Magnitude Comparison

Summary

- Playing War improved children’s symbolic numerical magnitude performance

- Head Start children in both numerical card conditions:
  - Improved their rote counting skills
  - Trended towards improving numeral identification skills

- There were no improvements on non-symbolic magnitude comparison tasks
  - Other studies have shown similar failures to “train” non-symbolic skills
    (Wilson, Dehaene, Dubois, & Fayol, 2009)
Summary

- Preschoolers performed near ceiling at pretest on rote counting and numeral identification tasks
  - Limited room for improvement on these measures

- Memory card game was an active control condition that included practice with numbers

Study Aims

- We examined with a larger sample whether playing numerical card games can improve Head Start children’s early numeracy skills compared to a non-numerical card game

- We examined whether the benefits extended to broader measures of numerical understanding

- (We examine whether the benefits lasted over a 2-month period)
Methods

- Participants: 81 Head Start preschoolers
  - 3 to 5-years old, \( M = 4 \) years, 6 months
  - 61% Hispanic/Latino, 23% African American/Black, 5% Asian, 1% Caucasian, 10% Multiracial

Four 15-minute sessions individually with an experimenter

- Numerical magnitude comparison card game (“War”)
- Numerical memory and matching card game (“Memory”)
- Non-numerical control game: Matching shapes and colors (Shape Uno)

Method

- Pre and Posttest Tasks (Sessions 1 and 6):
  - Rote counting (1 – 25)
  - Numeral identification (1 – 10)
  - Symbolic magnitude comparison
  - Non-symbolic magnitude comparison

- Enumeration
- Cardinality (Give X-Task)
Results

**Counting**

Correct Counts w/o Error

Pretest  Posttest

War  Memory  Shape Uno

** p < .01

**Number Identification**

Numbers Correctly Identified

Pretest  Posttest

War  Memory  Shape Uno

** p < .01

Results

**Symbolic Magnitude Comparison**

Percent Correct

Pretest  Posttest

War  Memory  Shape Uno

** p < .01

**Non-symbolic Magnitude Comparison**

Percent Correct

Pretest  Posttest

War  Memory  Shape Uno

*
Results

![Graphs showing improvement in enumeration and give X-task tasks](image)

* $p < .05$

Summary and Discussion

- Playing numerical card games for one hour led to significant improvements in low-income preschoolers' basic number skills

- Simple card games that could be easily implemented in schools, as well as in the home

- Stay tuned to see if the benefits are stable after not having played the game
Conclusions

• Playing games that target children’s numerical magnitude knowledge can lead to significant improvements in young children’s foundational number skills

• Both traditional games and tablet games can be useful activities for promoting young children’s numerical knowledge

• Theoretically guided informal learning activities and games have the potential to boost low-income students’ long-term academic performance, narrowing the mathematics achievement gap

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