Development of Executive Functioning and Math Skills

Education & Cognitive-Developmental Research at NIE

Kerry Lee

Head of Research
Education & Cognitive Development Lab
National Institute of Education

Academic Groups
- Asian Languages and Cultures
- Curriculum, Teaching and Learning
- Early Childhood and Special Needs Education
- English Language and Literature
- Humanities and Social Studies Education
- Learning Sciences and Technologies
- Mathematics and Mathematics Education
- Natural Sciences and Science Education
- Physical Education and Sports Science
- Policy and Leadership Studies
- Psychological Studies
- Visual and Performing Arts

Research Centres
- Centre for Research in Pedagogy & Practice
- Education & Cognitive Development Lab
- Learning Sciences Lab
- AG based research labs
Areas of Research

- Pure Basic Research
- Use-Inspired Basic Research (Strategic RD & I)
- Applied Research (Priority Innovation and Invention)
- Applied Research (Scaling Translation and Knowledge Management)

Focus of Investigation
- Student
- Classroom
- Teacher
- School
- National
- Regional & International
- Chronosystem

Core Baseline Tracking

Leadership & School Organisation

Teacher Learning

ICT Integration

Mathematics & Science

English Language & Mother Tongue Languages

Humanities

Applied Cognitive Development & Motivational Studies

Learning Sciences and Pedagogy

Assessment
Education & Cognitive Development Lab

Research Areas

Atypical Development/Disabilities/Children at Risk
- Kenneth Poon, Rebecca Bull, +1

Bilingual Development
- Beth O’Brien, Yin Bin, +1

Applied Cognitive Development
- Kerry Lee, Khng Kiat Hui, Rebecca Bull, Ang Su Yin

Intervention & Translational Science
- Jerome Rotgans, Alfredo Bautista

Supported by 30+ project based research assistants/associates/fellows
The impact of kindergarten on children’s developing abilities

Rebecca Bull & ECDL co-PIs
To examine *structural* and *process* factors as measures of quality in early childhood learning environments.

To understand how teacher-child interaction and structural factors relate to individual differences in the development of children’s socio-emotional, numeracy, literacy, language (EL & MT), self-regulation skills, and physical development.

To investigate the relation of home environment factors with child outcomes and to understand how the preschool environment might mediate early adverse conditions.

*Figure 1. Main aim of the study*
INHIBITION & ATTENTION

Fannie Khng Kiat Hui, Research Scientist
Effects and Mechanisms of a Deep Breathing Intervention for Test Anxiety

- Previous (behavioral) study
  - Taking deep breaths before a test significantly reduced feelings of (state) anxiety and improved performance
  - Hypothesized mechanisms

- However, behavioral data showed no changes in attentional focus
- Self-reported changes in state anxiety ≠ relaxation actually achieved

Follow-up study:
- EEG correlates
- Changes during deep breathing
- Changes in attention
Imaging as a Pedagogical Tool?
Near-infrared spectroscopy

- Measures blood oxygen level dependent response
- Possibility of examining pedagogical issues in situ
- Logic of experiments
  - Performance of cognitive task
  - Localised changes in cortical tissues
    - Increases in metabolism
    - Vasodilation
    - Changes in blood oxygenation level
    - Oxy vs. deoxy Hb have different light absorption properties
  - Allows visualisation of brain activity that correlates with the performance of cognitive tasks
Proof of Concept Study

- Problem size effect
  - RT and ACC differences
  - WM mediated

- Is NIRS sensitive to differences resulting from task difficulties?
  - Depth of penetration
  - Frontal unit
Method

• Participants
  o 21 healthy, right-handed adult participants

• Instrument
  o 16-channel NIRS
  o 4 tri-wavelength (730nm, 805nm, and 850nm) LEDs and 10 detectors, frequency = 3Hz
Task

- Manipulated task difficulty by varying the magnitude of the operands
- 75 questions
  - 5 x 15 randomized blocks

12 sec per qns x 5 qns = 60 sec

Easy Block (5 Questions)
- \(a + b = x\) or \(xy\)

Medium Block (5 Questions)
- \(ab + c = xy\)

Difficult Block (5 Questions)
- \(ab + cd = xy\)
Results

Fig 4. Schematic diagram of the experiment setup and arrangement of light sources (L) and detectors (1 - 16) on the probe.

Fig 7. Changes in [HbO2] in Ch 9 for all participants (N=21)

Fig 8. Changes in [HbO2] in Ch 11 for all participants (N=21)

a) No difference was found in Δ[deoxy-Hb] and Δ[Total-Hb].
b) Significant differences were found in [Oxy-Hb], particularly in channel 9 & 11. Blood oxygenation level increased with task.
Classroom Application?
Executive functioning & developing math skills
Two Strategies

• A cow weighs 150 kg more than a dog
• A goat weighs 130 kg less than the cow
• Altogether the three animals weigh 410 kg
• What is the mass of the cow?

Primary/Grade 5

Secondary 2/Grade 8

Ng & Lee (2009) Journal for Research in Mathematics Education
Why Algebra?

- In Singapore, algebraic word problem has an important role in the primary math curriculum
- Considerable variation in performance
  - Why?

- Pattern recognition
- Quantitative comparison
- Operation reversal

Bridge to symbolic algebra (taught in high school)
Doing the Right Thing?

• Considerable time and effort are expanded on teaching the model method in the primary years
• Is it worthwhile?
  • Yes
    • The model method help children acquire formal algebra
  • No
    • Children are taught to do the same thing twice
    • Multiple methods confuse children
• Programme evaluation
  • Impracticable
    • Model method has been part of the national curriculum for over ten years

\[
\begin{align*}
3 \text{ units} & \rightarrow 410 + 150 + 130 \\
& = 690 \\
1 \text{ unit} & \rightarrow 760 \div 3 \\
& = 230
\end{align*}
\]
Results

Similarities between the model & symbolic methods
Differences Between Methods

Areas activated by the symbolic method

Lee et al. (2007) Brain Research

Time courses of signal changes in the precuneus Threshold set at p < .001 (uncorrected)

Lee et al. (2010) ZDM
Behavioural Studies
Working Memory and Mathematical Performance

- Central executive measures predicted early mathematical performance
  - Bull, Johnston, and Roy (1999), Bull and Scerif (2001)
- Standardised working memory scores predicted children’s academic standing in mathematics with 83% accuracy
  - Gathercole and Pickering (2000)
Does Working Memory Explain Variance in Algebraic Performance?

Lee, Ng, Ng, & Lim (2004) *Jn Exp Child Psych*

* $p < .05$, ** $p < .01$,

$R^2 = .46$, CFI = .095, SRMR = .07

Participants: 151 10-year-olds
Are Some Aspects of Algebraic Problem Solving More Resource Intensive?

- A cow weighs 150 kg more than a dog
- A goat weighs 130 kg less than the cow
- Altogether the three animals weigh 410 kg
- What is the mass of the cow?

Overall accuracy \( \leftarrow \) WM

- \( R^2 = 0.26 \)

**Question Understanding**
- Identifying known vs. unknown, working out problem requirement,

- \( R^2 = 0.23 \)

**Quantitative Judgment**
- Which animal weighs more – the goat or the cow?

- \( R^2 = 0.19 \)

**Operator Selection**
- Associating quantitative relationship with appropriate arithmetic operation

**Computation**
- A cow weighs 150 kg more than a dog
- A goat weighs 130 kg less than the cow
- Altogether the three animals weigh 410 kg
- What is the mass of the cow?

**Solution Formation**
- From pictorial model to solution

- \( R^2 = 0.27 \)

**Representation Formation**
- From text to pictorial model

- \( R^2 = 0.26 \)

Lee, Ng, & Ng (2009) *Jn Educ Psych*
Is the Relation Causal?

- Dual task experiment
- Evidence of causal link

A Longitudinal Investigation
Research Question

• Are there age related differences in the role of working memory and updating?
  o Unless there are extended periods of revision and consolidation that results in a high level of automaticity, WM and updating resources will be needed for solution
  o From a predictive perspective, two possibilities
    • Math performance is dependent largely on building up domain specific skills and knowledge
      o => WM and updating supports computation of solution, but less so for acquisition
    • Alternatively, additional WM and updating resources may be needed during initial acquisition to support the learning of novel concepts
      o WM reduces in importance as subsequent learning becomes more dependent on prior knowledge
Constructs Tested

Executive functioning

Basic numeracy

Understanding of math patterns

Arithmetic

Algebra

Inhibition, switching

WM & updating

K2

Grade 9

General math achievement
## Cross-sequential Design

<table>
<thead>
<tr>
<th>Cohorts</th>
<th>Grades (Age)</th>
</tr>
</thead>
<tbody>
<tr>
<td>K2 (5)</td>
<td>P1 (6)</td>
</tr>
<tr>
<td>P2 (7)</td>
<td>P3 (8)</td>
</tr>
<tr>
<td>P2 (7)</td>
<td>P3 (8)</td>
</tr>
<tr>
<td>P4 (9)</td>
<td>P5 (10)</td>
</tr>
<tr>
<td>P4 (9)</td>
<td>P5 (10)</td>
</tr>
<tr>
<td>P6 (11)</td>
<td>S1 (12)</td>
</tr>
<tr>
<td>P6 (11)</td>
<td>S1 (12)</td>
</tr>
<tr>
<td>S2 (13)</td>
<td>S3 (14)</td>
</tr>
</tbody>
</table>

~ 673 children, over 4 cohorts; 81 school at Wave 4
**Instruments**

- **Executive functioning**
  - Inhibitory efficiency
    - Flanker
    - Simon
    - Antisaccade Mickey
  - Switching efficiency
    - Switch conditions from Flanker and Simon
    - Picture–symbol
  - Updating capacity
    - Running Span
    - Mr. X
    - Listening Recall

- **Standardised mathematical tasks**
  - Wechsler Individual Achievement Test
    - Number Operations
    - Mathematical Reasoning

- **Curricular based mathematical tasks**
  - Number patterns
  - Function machines
  - Functions
  - Arithmetic and algebraic word problems
Working Memory/
Updating Tasks
Complex Span Tasks

- **Mr. X (AMWA)**
  - Are the two figures holding their balls with the same hand? Remember where the figure with the blue hat holds the ball.

- **Listening Span (AMWA)**
  - Listen to each statement. At the end of each statement, tell me whether it is true or false. When I have finished reading all x statement(s), please tell me the last word in each statement.
    - Bananas live in water (T/F)
    - Flowers smell nice (T/F)
Which were the last two animals that you saw?

Animal Updating
- Children were shown an unknown number of animals one at a time. They were then asked to remember the last 2, 3, or 4 animals.
Math Tasks
<table>
<thead>
<tr>
<th>Grade level</th>
<th>Sample items from the WIAT – Numerical Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kindergarten to Primary 1</td>
<td>1 2 3 _ 5 6 7 8 9</td>
</tr>
<tr>
<td>Lower Primary (P1 to P3)</td>
<td>4 + 5 = ___ 150 - 25 4 X 3 = ___</td>
</tr>
<tr>
<td>Upper Primary (P4 to P6)</td>
<td>7)861 .4 + .6 = ___ 1/3 - 1/4 = ___</td>
</tr>
<tr>
<td>Secondary (S1 and above)</td>
<td>10^2 = ___ -14 + (-16) = ___ 2x - 15 = 3 - x x = ___</td>
</tr>
</tbody>
</table>
Number Patterns

Q7
9   10   11   _____   13

7. 324 675, 344 675, 364 675, _____, 404 675

20 | a, 2(a + d), 3a + 4d, 2(2a + 3d), _____, _____, _____  

Ng (2010)
Algebra Word Problems

Edwin spent $\frac{3}{4}$ of his money on books. He spent $48$ on books. How much money had he at first?

In 4 years’ time, Mr Wong will be 3 times as old as his son. 4 years ago he was 5 times as old as his son. How old is Mr Wong now?
Findings: Cross-sectional
WM & General
Math Achievement

Correlation ratios

Grades

WMU
Mr. X
Animal Updating
Listening Recall

Numerical Operations
WM, Relational Skills, & Algebra

Correlation ratios

Grades

4 5 6 7 8 9

0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
Findings: Predictive
WM & General Math Achievement

- Crosslagged relations between WM-updating and WIAT remained the same across grades.
- Autoregressive relation between each year’s math performance is lower between Grade 1 and kindergarten.
  - The predictive power of WM-updating is relatively larger in the earlier grades.

Lee & Bull (2015) under review
WM, Relational Skills, & Algebra

Autoregressive-crosslagged model
Estimated parameters = 251,
\[ X^2 (1324) = 1828.632, \ p < .001 \]
RMSEA = .049
CFI = .931
SRMR = .120
WM & General Math Achievement

• From a task performance perspective
  • WM-updating relatively more important in the first years of formal schooling

• From an acquisition perspective
  • Actual predictive power of WM-updating remained the same across grades
  • Relative predictive power of WM and updating capacity varies across grades
The role of WM/U seems to differ across the cross-sectional and predictive analyses:

- Cross-sectional
  - WM needed for the execution of both patterns and algebra questions
- Predictive
  - No impact on learning of algebra with the exception of Grade 8 and 9
    - Negative relation for Grade 8
    - Positive relation for Grade 9

**Working interpretation**

- Children taught to solve very similar algebraic questions in more junior grades using arithmetic unwinding methods.
- More able children are particularly well practiced and successful with the arithmetic methods:
  - They may have difficulty letting go of a successful strategy and adjust to symbolic algebra.
  - There was a general decrease in performance accuracy at this grade, from .48 at Grade 7 to .40.
  - Ability to switch and inhibit correlated weakly to moderately with both algebra and relational performances.
- With more experience, these children again surge ahead in S3.
Future Directions

• Findings regarding the role of WM & updating at Grades 8 and 9 are intriguing
  o Need to examine how children with different WM capacity solve algebra questions as they transit from an arithmetic to a symbolic approach to algebra

• The role of inhibitory abilities is intriguing
  o Conceptually important, but difficult to demonstrate empirically
    • Measurement issues?