Correlational data analysis in cognitive development:
The primacy of risky tests

Drew Bailey
University of California, Irvine
Bob’s Postdoc, 2012-2014
Some important things I learned from Bob
Some important things I learned from Bob

• The importance of understanding *processes* in cognitive development
Some important things I learned from Bob

• The importance of understanding *processes* in cognitive development

A useful analogy for (some) correlational data analysis in cognitive development?
Some important things I learned from Bob

- The importance of understanding *processes* in cognitive development

A useful analogy for (some) correlational data analysis in cognitive development?
Some important things I learned from Bob

• The importance of understanding *processes* in cognitive development

A useful analogy for (some) correlational data analysis in cognitive development?

Phase 1: Boost early math learning.

Phase 2: ?

Phase 3: Profit.
Some important things I learned from Bob

• The importance of understanding *processes* in cognitive development

A useful analogy for (some) correlational data analysis in cognitive development?

Phase 1: Boost early math learning.

Phase 2: **Skill building?**

Phase 3: Profit.
Skill Building

Counting  Counting all
1 2 3 4 5 ... 2 + 3 = 1 2 3 4 5

Baroody, 1987
Skill Building

Counting
1 2 3 4 5 ...

Counting all
$2 + 3 = 1 2 3 4 5$

Counting min
$2 + 3 = 3... 4 5$

Baroody, 1987
Skill Building

Counting  
1 2 3 4 5 …

Counting all
2 + 3 = 1 2 3 4 5

Counting min
2 + 3 = 3 … 4 5

Retrieval
2 + 3 = 5

Baroody, 1987
Skill Building

Counting
1 2 3 4 5 ...

Counting all
2 + 3 = 1 2 3 4 5

Counting min
2 + 3 = 3… 4 5

Retrieval
2 + 3 = 5

Baroody, 1987
Addition as subroutine of multiplication
(Lemaire & Siegler, 1995)
Earlier Mathematics Achievement (e.g., Aunola, Leskinen, Lerkkanen, & Nurmi, 2004; Duncan et al., 2007; Geary, Hoard, Nugent, & Bailey, 2013; Jordan, Kaplan, Ramineni, & Locuniak, 2009; Watts, Duncan, Siegler, & Davis-Kean, 2014)

Later Mathematics Achievement

Controls: IQ, working memory, reading achievement, SES, others

+$+$
Earlier Mathematics Achievement

Later Mathematics Achievement

What does this mean?
Varying degrees of causal interpretation and/or policy prescriptions in discussion sections (see Reinhart et al., 2013)
Is this a risky test of skill building theories?
Risky tests

• Prior probability of $x$, absent theory, should be small
Risky tests

• Prior probability of $x$, absent theory, should be small

• Predictions following Meehl’s theory of weather:

  April rain $> 0$.

  April rain $> May$ rain ($p < .001$).

  It will rain 5 days in April.

  It will rain April 1, 7, 14, 15, 26, and no other days.
Risky tests

- Prior probability of \( x \), absent theory, should be small
- Predictions following Meehl’s theory of weather:

  \[
  \begin{align*}
  \text{April rain} & > 0. \\
  \text{April rain} & > \text{May rain (} p < .001 \text{!)}.
  \end{align*}
  \]

  \[
  \text{It will rain 5 days in April.}
  \]

  \[
  \text{It will rain April 1, 7, 14, 15, 26, and no other days.}
  \]
Risky tests

- Prior probability of $x$, absent theory, should be small

- Predictions following Meehl’s theory of weather:

  April rain $> 0$

  April rain $> May$ rain ($p < .001$).

  It will rain 5 days in April.

  It will rain April 1, 7, 14, 15, 26, and no other days.
Earlier Mathematics Achievement

Later Mathematics Achievement

Controls:
IQ, working memory, reading achievement, SES, others

Is this a risky test of skill building theories?
Earlier Mathematics Achievement

Controls:
IQ, working memory, reading achievement, SES, others

Later Mathematics Achievement

Other stuff

Boring, plausible alternative theory
Earlier Mathematics Achievement

Later Mathematics Achievement

Controls: IQ, working memory, reading achievement, SES, others

Boring, plausible alternative theory
Earlier Mathematics Achievement (Controls: IQ, working memory, reading achievement, SES, others) → + → Later Mathematics Achievement

Other stuff

Boring, plausible alternative theory
Earlier Mathematics Achievement

Later Mathematics Achievement

Controls: IQ, working memory, reading achievement, SES, others

Other stuff

Boring, plausible alternative theory
Does it matter? Maybe, when + minus + is big
Earlier Mathematics Achievement vs. Later Mathematics Achievement

Controls:
IQ, working memory, reading achievement, SES, others
Early math predicts much later math.
Early math predicts much later math.

Early math predicts much later reading about as well.
Figure 1: Bivariate correlations with Fall of Kindergarten measures

Source: ECLS-K 1998-1999 cohort. All correlations are p<.05
Figure 1: Bivariate correlations with Fall of Kindergarten measures

Source: ECLS-K 1998-1999 cohort. All correlations are p<.05

Duncan et al. (2007): Reading to reading: .24
Figure 1: Bivariate correlations with Fall of Kindergarten measures

Source: ECLS-K 1998-1999 cohort. All correlations are p<.05

Duncan et al. (2007): Reading to reading: .24
Math to reading: .26
Earlier Mathematics Achievement vs. Later Mathematics Achievement

Controls: IQ, working memory, reading achievement, SES, others

Other stuff

Early math predicts much later math.

Early math predicts much later reading about as well.
Earlier Mathematics Achievement + Later Mathematics Achievement

Controls: IQ, working memory, reading achievement, SES, others

vs.

Earlier Mathematics Achievement + Later Mathematics Achievement

Controls: IQ, working memory, reading achievement, SES, others

Other stuff

Early math predicts much later math.

Early math predicts much later reading about as well.

Early math predicts proximal math better than distal math.
Controls: pre-k entry math, SES, ELL status, pre-k entry age
Controls: pre-k entry math, SES, ELL status, pre-k entry age

Bailey et al. (2014), SECCYD:
\[ r(\text{Grade 1, Grade 3}) = 0.72 \]
Controls: pre-k entry math, SES, ELL status, pre-k entry age

Bailey et al. (2014), SECCYD:
\[ r(\text{Grade 1, Grade 3}) = .72 \]
\[ r(\text{Grade 1, Age 15}) = .66 \]
Bailey et al. (2014), SECCYD:
- $r(\text{Grade 1, Grade 3}) = .72$
- $r(\text{Grade 1, Age 15}) = .66$

Duncan et al. (2007), average math-math adjusted correlation = .42

Controls: pre-k entry math, SES, ELL status, pre-k entry age
Earlier Mathematics Achievement $\rightarrow$ Later Mathematics Achievement

Controls: IQ, working memory, reading achievement, SES, others

Early math predicts much later math.  
Early math predicts much later reading about as well.  
Early math predicts proximal math better than distal math.
Earlier Mathematics Achievement \( \rightarrow \) Later Mathematics Achievement

\text{Controls: IQ, working memory, reading achievement, SES, others}

\text{Early math predicts much later math.}

\text{Early math predicts much later reading about as well.}

\text{Early math predicts proximal math better than distal math.}

\text{Could early skills have \textit{direct} effects on much later achievement?}
Earlier Mathematics Achievement \rightarrow \textbf{Later Mathematics Achievement}

- \textbf{vs.}

- \textbf{vs.}

\textbf{Controls:}
IQ, working memory, reading achievement, SES, others

- \textbf{vs.}

\textbf{Earlier Mathematics Achievement} \rightarrow \textbf{Later Mathematics Achievement}

\textbf{Other stuff}

\checkmark \text{ Early math predicts much later math.}

\times \text{ Early math predicts much later reading about as well.}

\checkmark \text{ Early math predicts proximal math better than distal math.}

- \textbf{vs.}

- \textbf{vs.}

\textbf{Could early skills have \textit{direct} effects on much later achievement?}

\textbf{Growth is fast in early math:} > 2 \textit{SD} from K-2 (Hill, Bloom, Black, & Lipsey, 2008);
Earlier Mathematics Achievement vs. Later Mathematics Achievement

Controls:
IQ, working memory, reading achievement, SES, others

Early math predicts much later math.
Early math predicts much later reading about as well.
Early math predicts proximal math better than distal math.

Could early skills have direct effects on much later achievement?
Growth is fast in early math: > 2 SD from K-2 (Hill, Bloom, Black, & Lipsey, 2008); counting is mastered by most kindergarteners (Engel, Claessens, & Finch, 2013)
Earlier Mathematics Achievement vs. Later Mathematics Achievement

Controls:
IQ, working memory, reading achievement, SES, others

- Early math predicts much later math.
- Early math predicts much later reading about as well.
- Early math predicts proximal math better than distal math.
- Early math intervention effects persist at levels predicted by regression analyses.
controls: IQ, working memory, reading achievement, SES, others

vs.

controls: IQ, working memory, reading achievement, SES, others

Early math predicts much later math.

Early math predicts much later reading about as well.

Early math predicts proximal math better than distal math.

Early math intervention effects persist at levels predicted by regression analyses.
Controls: pre-k entry math, SES, ELL status, pre-k entry age
Math Achievement (Scaled to 1-SD effect at end of prek) vs Age (years)

- TRIAD Correlations
- TRIAD Tx Impacts
Early math predicts much later math.
Early math predicts much later reading about as well.
Early math predicts proximal math better than distal math.
Early math intervention effects persist at levels predicted by regression analyses.
Methods: can we do better than this?
Earlier Mathematics Achievement \(\rightarrow\) Later Mathematics Achievement

Controls: IQ, working memory, reading achievement, SES, others

vs.

Earlier Mathematics Achievement \(\rightarrow\) Later Mathematics Achievement

Controls: IQ, working memory, reading achievement, SES, others

Other stuff

Methods: can we do better than this?

i.e., how do we account for this?
Latent state-trait model (Steyer, 1987)
Math skill at time 1: 1

Latent state-trait model (Steyer, 1987)
Predicted standardized treatment effects on math skill following 1 SD boost in Math skill at time 1:

- Math skill at time 1: 1
- Math skill at time 2: $MS_1$

Latent state-trait model (Steyer, 1987)
Unmeasured persistent factor

Math skill at time 1

Math test time 1

Math skill at time 2

Math test time 2

Math skill at time 3

Math test time 3

Predicted standardized treatment effects on math skill following 1 SD boost in Math skill at time 1:

Math skill at time 1: 1
Math skill at time 2: $MS_1$
Math skill at time 3: $MS_1 * MS_2$

Latent state-trait model (Steyer, 1987)
Average 1-year $MS$ estimate from 3 datasets analyzed in Bailey et al., 2014; Watts et al. (under review): .35
TRIAD Correlations

State/Trait Model

Aggregated

Experimental

TRIAD Tx Impacts

Math Achievement (Scaled to 1-SD effect at end of prek)

Age (years)
Conclusions

Earlier Mathematics Achievement vs. Later Mathematics Achievement

Controls: IQ, working memory, reading achievement, SES, others

Other stuff
Conclusions

Earlier Mathematics Achievement $\rightarrow$ Later Mathematics Achievement

Controls: IQ, working memory, reading achievement, SES, others

$+$

Earlier Mathematics Achievement $\rightarrow$ Later Mathematics Achievement

Controls: IQ, working memory, reading achievement, SES, others

$+$

Other stuff

$\times$

$\checkmark$
Conclusions

Unmeasured persistent factor

Math skill at time 1
Math skill at time 2
Math skill at time 3

Math test time 1
Math test time 2
Math test time 3

Predicted standardized treatment effects on math skill following 1 SD boost in Math skill at time 1:
Conclusions

No reason to think this is the ideal specification. Let’s try others.
Conclusions

Unmeasured persistent factor

Predicted standardized treatment effects on math skill following 1 SD boost in Math skill at time 1:

Math skill at time 1: $MS_1$

Math skill at time 2: $MS_2$

Math skill at time 3:

We don’t know what this is.
Conclusions

We don’t know what this is.

Bailey et al., 2014
Conclusions

Watts et al., under review

We don’t know what this is.
Conclusions

RCTs and quasi-experiments can provide the riskiest tests.
Conclusions

RCTs and quasi-experiments can provide the riskiest tests. Make correlational tests as risky as possible.
Earlier Mathematics Achievement → Later Mathematics Achievement

Controls: IQ, working memory, reading achievement, SES, others

vs.

Earlier Mathematics Achievement + Later Mathematics Achievement

Controls: IQ, working memory, reading achievement, SES, others

Other stuff

Early math predicts much later math.

Early math predicts much later reading about as well.

Early math predicts proximal math better than distal math.

Early math intervention effects persist at levels predicted by regression analyses.

Needed: contrasting theories; riskier tests
Some acknowledgments

- Tyler Watts
- Greg Duncan
- Andrew Littlefield
- Dave Geary
- Doug Clements, Julie Sarama, Christopher Wolfe, Mary Elaine Spitler
Final acknowledgment

To Bob,
for demanding more of me, and
for teaching me to demand more of myself