Cutting-Edge Quantitative and Computational Methods for STEM Education Research

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• NSF summer institute in advanced methods for STEM education research (2020-2023)

https://voices.uchicago.edu/nsf-siarm/

Still accepting applications: only a few spots left!

• Support a diverse cohort of NSF Fellows selected among early- and mid-career scholars in STEM education research

• Focus on understanding the sources of unequal access to STEM learning opportunities and evaluating strategies for transforming STEM education to advance equity and inclusion
Theories and Methods

To investigate complex phenomena in STEM education

Requires an ambitious research agenda

That examines competing theories

With sufficient scientific rigor
Hypothetical Case: Curricular Innovation

Context:
A new science curriculum (e.g., aligned with Next Generation Science Standards) for urban high schools designed to improve science learning and reduce achievement gaps between student demographic groups
[represents a range of issues that might come up in any given study]

Research Interests:
- How was the new curriculum implemented?
  School as an organization
- Does the new curriculum work?
  Engagement
  Achievement
- Why does it work or not?
- For whom and under what conditions?
Theoretical Model for Curricular Innovation

- Curriculum
- Teachers’ practice
- Student engagement
- Student learning
- Professional development
Research Questions

(1a) How was the new curriculum implemented?
(1b) Does the new science curriculum increase student engagement?
   And what are indicators of engagement?
Research Questions

(2) Does the new science curriculum improve student learning?
Research Questions

(3) Does the impact of the new science curriculum on student learning depend on the effectiveness of professional development?

Professional development may be independent of the curriculum
Research Questions

(5) How does the new science curriculum potentially transform teachers’ practice with support from professional development?
Research Questions

(4) Does the new science curriculum improve student learning through improving teachers’ practice?
Research Questions

(6) Does the new curriculum improve science achievement through improving teachers’ practice only if teachers have received effective professional development?
Major Methodological Considerations

Research Design
- Is random sampling feasible?
- Is randomization of the treatment feasible?
- If so, a cluster randomized trial or a multisite randomized trial?
- Cross-sectional or longitudinal? One cohort or multi-cohort?
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Major Methodological Considerations

- Teacher content knowledge of teaching
- Teacher-student relationship
- Enacted curriculum
- Student engagement

Yanyan Sheng
Major Methodological Considerations

Investigating Theoretical Mechanisms

Curriculum

Professional development

Instruction

Student learning

Moderation?  Mediation?  Moderated Mediation?

Guanglei Hong
Major Methodological Considerations

- Schools as organizations
- Teachers as agents
- Communities as contexts
- Students interact with one another

Steve Raudenbush
Major Methodological Considerations

- Teachers’ adoption of innovations influenced by other teachers they talk to
- Teachers change who they talk to as they change their instructional practices
- Social dynamics

Ken Frank
Major Methodological Considerations

- Research design and causal inference
- Measurement (Yanyan Sheng)
- Causal mediation analysis (Guanglei Hong)
- Multilevel modeling (Stephen Raudenbush)
- Social network analysis (Kenneth Frank)
- Computational methods (Kaitlin Torphy Knake)
Introduction to Causal Inference

Guanglei Hong

University of Chicago
Causal Inference: A Conceptual Framework

Define the causal effect of the new curriculum on science learning for *Julio*

- Potential achievement score if *Julio* would be taught with the **new** curriculum
- Potential achievement score if *Julio* would be taught with the **current** curriculum
Causal Inference: A Conceptual Framework

Define the causal effect of the new curriculum on science learning for the population of students

**Population average potential science score if all students would be taught with the new curriculum** — **Population average potential science score if all students would be taught with the current curriculum**
The Fundamental Problem with Causal Inference

• For each student, only one of the two potential outcomes can be observed; the other will be *counterfactual*

• Identification: using *observed* quantities to approximate *counterfactual* quantities under key *assumptions* (that often cannot be empirically verified)

• Which *assumptions* to invoke depends on the research design

• The causal effect is NOT identified if the *assumptions* FAIL; hence the need for *sensitivity analysis*
Identification Threatened by Selection Bias

Students with **Current** Curriculum

Students with **New** Curriculum

*less motivated or less skilled teachers*

*more motivated or more skilled teachers*
Treatment Selection in a Quasi-Experimental Study

Teacher Quality

Total

New Curriculum

Current Curriculum
Treatment Assignment in a Randomized Experiment
Two Different Rationales of Causal Inference

Under the **identification assumption** that measures of teacher quality are the only confounders

- **First Rationale**: Pool conditional mean difference
  - Multiple regression
  - Propensity score-based matching, stratification, or covariance adjustment
First Rationale: Pool Conditional Mean Difference
Two Different Rationales of Causal Inference

Under the identification assumption that measures of teacher quality are the only confounders.

• **Second Rationale:** Transform the pretreatment composition of each treatment group through weighting to resemble the pretreatment composition of the overall sample.
Weighting-Based Adjustment

For identifying the average treatment effect
Weighting-Based Adjustment

After Weighting
(approximating a completely randomized experiment)
Pop Quiz

How is the assumption of “no omitted confounder” like Alexander Hamilton?

They will never be satisfied!
Sensitivity Analysis after adjusting for teacher quality

A. Observed science learning under the new curriculum

B. Counterfactual learning under the current curriculum

C. Observed learning under the current curriculum

Effect:

Bias:

If pre-existing differences between the treated group and the untreated group remain, then

\[ \text{Bias} = B - C \neq 0 \]

The greater the bias relative to the effect, the more sensitive the initial causal conclusion would be to the omitted confounding.
The Confounding Impact of Student SES

Accounting for the Dual Relationships Associated with the Confounder
A Sensitivity Analysis Asks:

1) How large would a hidden bias need to be to alter the initial conclusion?

2) Is such a hidden bias scientifically plausible?

Fill in the blanks:

• A causal conclusion is considered to be sensitive if a relatively ________ (small or large?) bias would lead to a qualitative change in the conclusion because such a hidden bias is highly plausible.

• Conclusions that are harder to alter by a hidden bias are expected to add a ________ (lower or higher?) value to scientific knowledge.
RL-1 *What Would it Take to Change Your Inference? Quantifying the Discourse about Causal Inferences in the Social Sciences*

**INSTRUCTOR** Kenneth Frank, *Michigan State University*

**KonFound-It!**

Quantify the Robustness of Causal Inferences

[http://konfound-it.com](http://konfound-it.com)
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