Multilevel mediation modeling of a new inquiry-based approach to teaching science

Presenter: Mack Shelley

Luke Fostvedt, Marcia Laugerman, Brian Hand, William Therrien, Christopher Gonwa-Reeves, Dai-Trang Le

Iowa State University

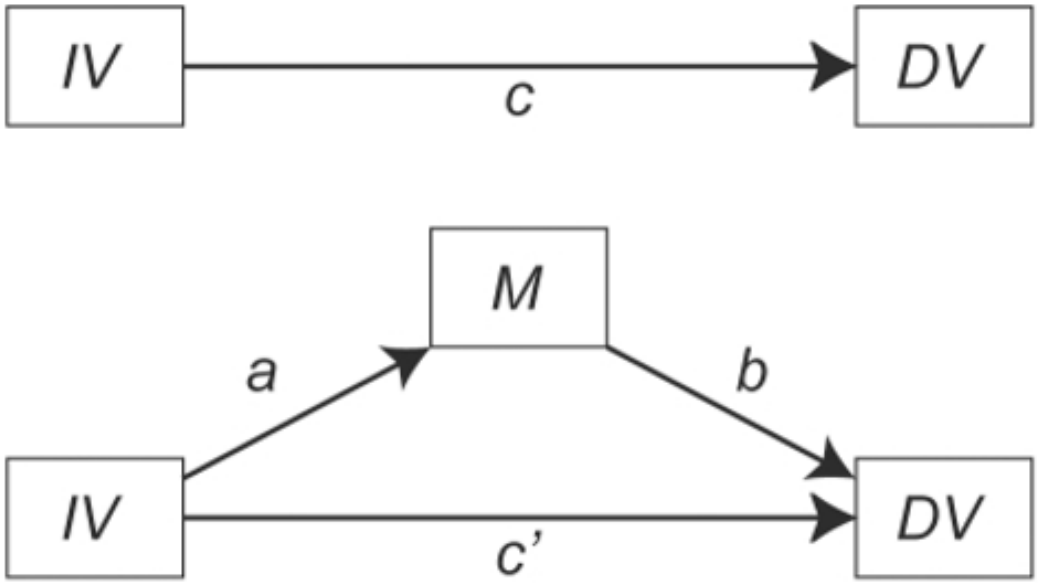
April 2, 2014

Background and Purpose

- Investigating a new approach to teaching science*
  - Intervention is applied at school level (Level 3)
  - Collect measure of teacher quality - rate video (Level 2)
  - Collect student test scores (Level 1)
- Questions:
  - Did the intervention improve student test scores?
  - Did teacher with high levels of implementation have higher achieving students

*Research funded by a grant from the US Department of Education through the Institute of Education Sciences, award number R305A090094-10. All opinions are those of the authors and do not necessarily reflect the views of the Institute of Education Sciences or the US Department of Education.

Model



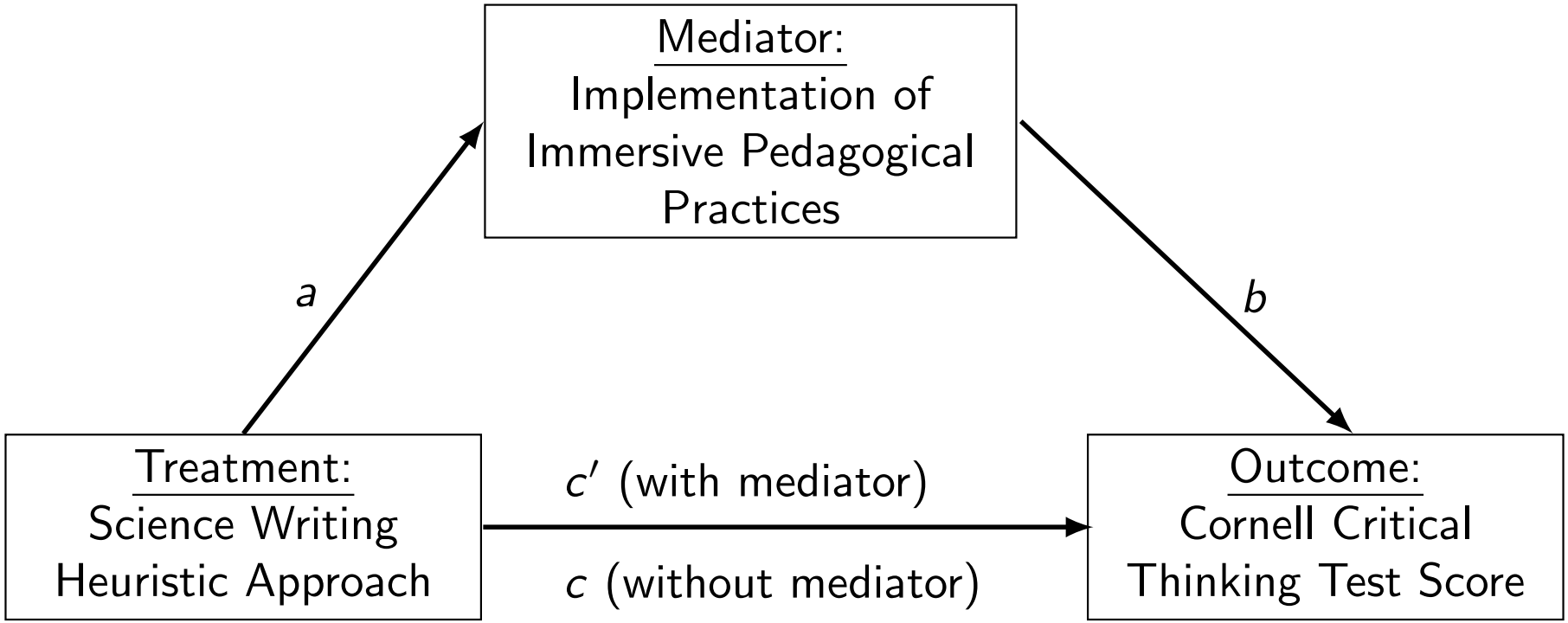
The figure above depicts a basic mediation model, in which the treatment (IV) is a cause of the mediator (M), which is hypothesized to be causally related to an outcome (DV). We use a $3 \rightarrow 2 \rightarrow 1$ mediation design (Pituch et al., 2010), with treatment assignment at level 3 (school), the mediator at level 2 (teacher), and the outcome of interest at level 1 (student).

$$\begin{array}{ccccc} \text{Total effect} & = & \text{Indirect effect} & + & \text{Direct effect} \\ c & = & ab & + & c' \end{array} \tag{1}$$

Example

- Application to data from study investigating a new approach to teaching science.
  - Intervention/Treatment: New approach to teaching science assigned to buildings
  - Mediator: Measure of teacher quality from video ratings
  - Outcome: Student scores from Cornell Critical Thinking Test
- Question: Does the quality of teacher implementation mediate the efficacy of the intervention?

Mediation Path Model



Student Covariates:
Free and Reduced-Price Lunch
English Language Learner
Individualized Education Program
Gifted and Talented
Gender

Path c

To estimate the effect of the intervention on the response without controlling for any possible mediating effect, we have the following 3-level model formulation: The student-level equation for the outcome is

$$Y_{ijk} = \pi_{0jk} + \pi_{1ik} \text{ Covariates} + e_{ijk}$$

The class-level equation adds a random intercept for each class

$$\begin{aligned} \pi_{0jk} &= \beta_{0jk} + r_{0j} \\ \pi_{1jk} &= \beta_{01k} \text{ Covariates} \end{aligned}$$

The school-level equations are

$$\begin{aligned} \beta_{00k} &= \gamma_{000} + \gamma_{001} T_k + u_{00k} \\ \beta_{01k} &= \tilde{\gamma} \text{ Covariates} \end{aligned}$$

Path *a*

Since the mediator is measured at the class level, only two levels - class and school - are needed in the model for the mediator.

$$M_{jk} = \beta_{0k} + r_{jk}$$

where M_{jk} is the observed rating for the quality of inquiry based teaching for teacher j in school k.
The school level, level-2, model is:

$$\beta_{0k} = \gamma_{00} + \gamma_{01} T_k + u_{0k}$$

where γ_{00} is the mean quality of inquiry based teaching at a control school and γ_{01} is the effect of the intervention on the mediator.

Paths c' and b

The equations for the outcome, needed to estimate paths b and c' of Figure 1, have student, class, and school levels. The student-level equation for the outcome is

$$Y_{ijk} = \pi_{0jk} + \pi_{1ik} \text{ Covariates} + e_{ijk}$$

The class-level equation adds the mediator as an explanatory variable and is

$$\begin{aligned} \pi_{0jk} &= \beta_{00k} + \beta_{01k} M_{jk} + r_{0jk} \\ \pi_{1jk} &= \beta_{02k} \text{ Covariates} \end{aligned}$$

The school-level equations are

$$\begin{aligned} \beta_{00k} &= \gamma_{000} + \gamma_{001} T_k + u_{00k} \\ \beta_{01k} &= \gamma_{010} + u_{01k} \\ \beta_{02k} &= \tilde{\gamma} \text{ Covariates} \end{aligned}$$

Path c - without mediator

Fixed Effects	Coefficient	SE	p-value
Mean CCT Improvement (γ_{000})	3.937	0.425	<0.001
TRT effect on CCT Improvement (γ_{001})	1.090	0.508	0.032
Special Education Gap (γ_{010})	-1.814	0.498	<0.001
Gifted and Talented Gap (γ_{011})	0.235	0.488	0.630
English Language Learner Gap (γ_{012})	0.210	1.111	0.850
Free and Reduced Lunch Gap (γ_{013})	-0.220	0.356	0.536
Gender (γ_{014})	-0.391	0.335	0.244
Final Random Effects	**Variance Components**		**% Total**
School-level (u_{00k})	1.492		3.19%
Teacher-level (r_{0jk})	0.555		1.19%
Student-level (e_{ijk})	44.708		95.62%

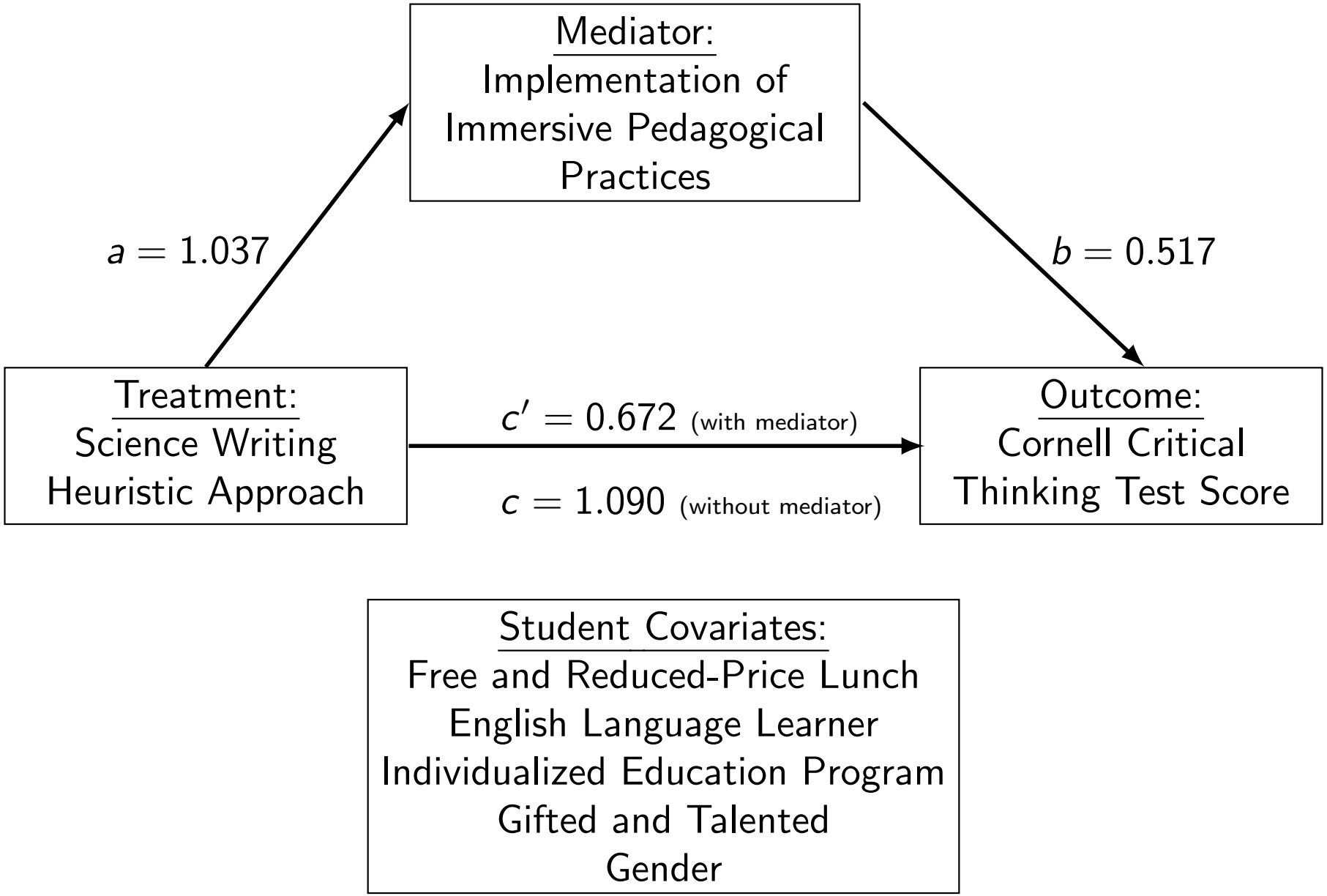
Path *a* - treatment on mediator

Fixed Effects	Coefficient	SE	p-value
Mean Teacher Rating (γ_{00})	0.157	0.160	0.328
TRT effect Teacher Rating (γ_{01})	1.037	0.197	$<$0.001
Final Random Effects	**Variance Components**		**% Total**
School Level (r_{jk})	0.066		23.83%
Teacher Level (u_{0k})	0.211		76.17%

Path b and c' - including mediator

Fixed Effects	Coefficient	SE	p-value
Mean CCT Improvement (γ_{000})	3.819	0.452	$<$0.001
TRT effect on CCT Improvement (γ_{001})	0.672	0.684	0.326
Teacher Implementation Rating (γ_{010})	0.517	0.440	0.240
Special Education Gap (γ_{020})	-1.798	0.493	$<$0.001
Gifted and Talented Gap (γ_{021})	0.239	0.493	0.628
English Language Learner Gap (γ_{022})	0.250	1.110	0.821
Free and Reduced Lunch Gap (γ_{023})	-0.204	0.354	0.564
Gender Gap (γ_{024})	-0.393	0.331	0.236
Final Random Effects	**Variance Components**		**% Total**
Level-1 School Effect (u_{00k})	2.272		4.76%
Teacher Implementation Rating (u_{01k})	0.248		0.52%
Level-2 Teacher Effect (r_{0jk})	0.384		0.80%
Level-3 Student Effect (e_{ijk})	44.760		93.91%

Mediation Path Model



Path *ab* - Indirect Effect

The indirect effect, averaging across schools, is represented by the *ab* product, which is $\gamma_{01}\gamma_{010}$. This standard expression for the indirect effect holds because path *a* is at the highest level of the design and cannot vary across upper level units. Thus, paths *a* and *b* cannot co-vary in this design.

The uncertainty associated with path *ab* is calculated using the Sobel (1982) standard error. This standard error is $\sqrt{a^2 o_b^2 + b^2 o_a^2}$, where a and b represent paths *a* and *b*, and o_a and o_b represent the standard error of these paths.

Path *ab* - Mediator

- The indirect effect represented by the *ab* product is

$$\gamma_{01}\gamma_{010} = (1.037) \times (0.517) = 0.531$$

- The Standard Error of the indirect effect is

$$\begin{aligned} \sqrt{a^2 o_b^2 + b^2 o_a^2} &= SE \\ \sqrt{(1.037)^2(0.508)^2 + (0.517)^2(0.197)^2} &= 0.5365 \end{aligned}$$

- 95% Confidence Interval: (-0.521, 1.53)

Conclusions

- Implementation (Mediator) was not a significant influence on student outcomes
- Student outcomes are robust with respect to teacher implementation
- Rather, the key point is that what matters is that the inquiry-based approach was implemented

Mack Shelley (co-PI): mshelley@iastate.edu
Bill Therrien (co-PI): bill-therrien@uiowa.edu
Brian Hand (PI): brian-hand@uiowa.edu