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The Effects of the 5E Instructional Model: A Systematic Review and Meta-Analysis

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The 5E Instructional Model

- Based in tenets of developmental psychology, social constructivism
- Draws on seminal work of Dewey, Piaget, and particularly Atkin & Karplus (1962)

Table 1. Summary of the BSCS 5E Instructional Model

Phase	Summary
Engagement	The teacher or a curriculum task accesses the learners' prior knowledge and helps them become engaged in a new concept through the use of short activities that promote curiosity and elicit prior knowledge. The activity should make connections between past and present learning experiences, expose prior conceptions, and organize students' thinking toward the learning outcomes of current activities.
Exploration	Exploration experiences provide students with a common base of activities within which current concepts (i.e., misconceptions), processes, and skills are identified and conceptual change is facilitated. Learners may complete lab activities that help them use prior knowledge to generate new ideas, explore questions and possibilities, and design and conduct a preliminary investigation.
Explanation	The explanation phase focuses students' attention on a particular aspect of their engagement and exploration experiences and provides opportunities to demonstrate their conceptual understanding, process skills, or behaviors. This phase also provides opportunities for teachers to directly introduce a concept, process, or skill. Learners explain their understanding of the concept. An explanation from the teacher or the curriculum may guide them toward a deeper understanding, which is a critical part of this phase.
Elaboration	Teachers challenge and extend students' conceptual understanding and skills. Through new experiences, the students develop deeper and broader understanding, more information, and adequate skills. Students apply their understanding of the concept by conducting additional activities.
Evaluation	The evaluation phase encourages students to assess their understanding and abilities and provides opportunities for teachers to evaluate student progress toward achieving the educational objectives.

Source: Bybee et al. 2006

Variants on the 5E Instructional Model

Elicit

Engage

Explore

Explain

Elaborate

Evaluate

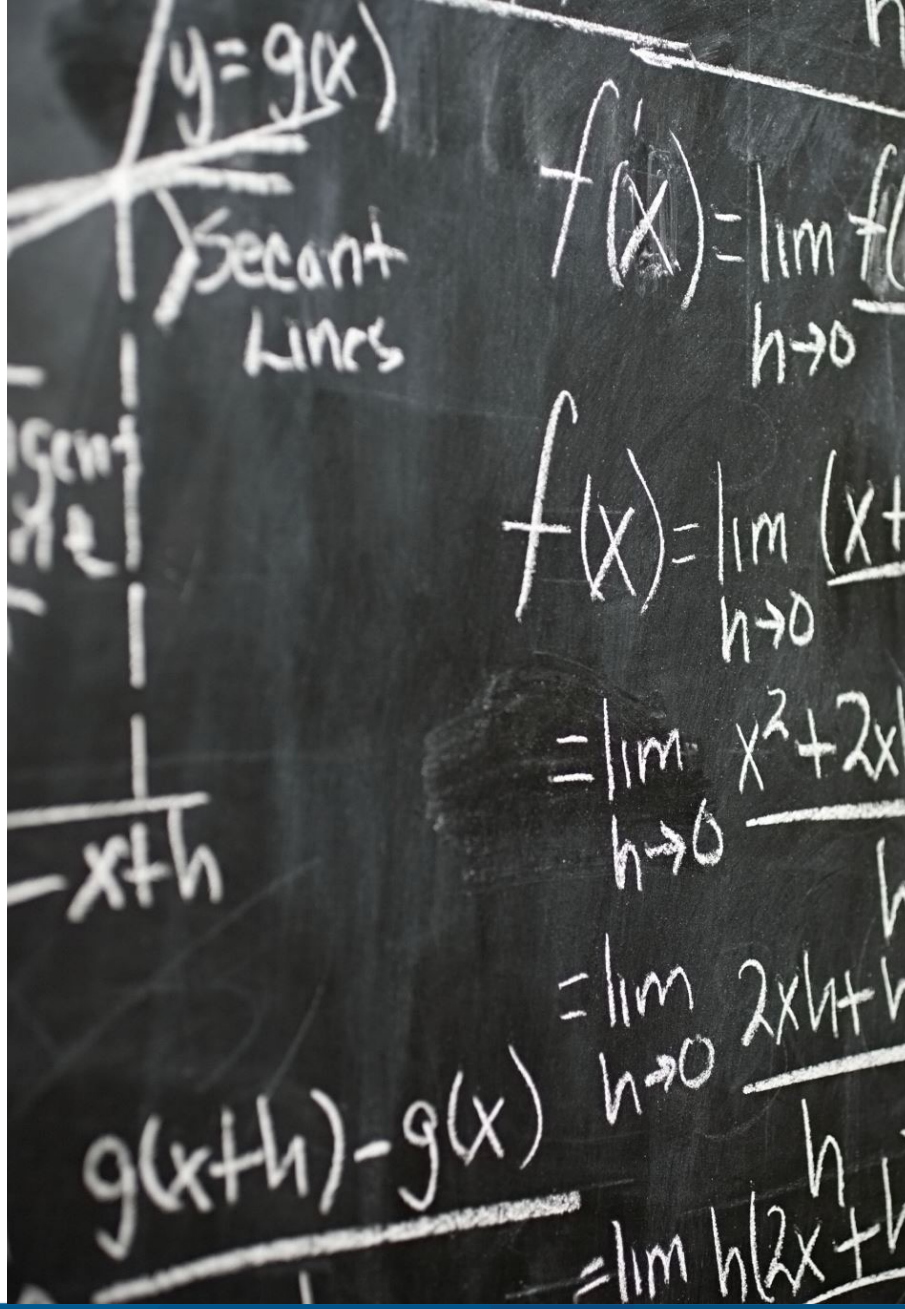
Extend

The 7E model makes more explicit the elicitation of prior knowledge and *far* transfer elaboration activities

Research Questions/Study Purpose

1. What are the average effects of interventions based on the 5E instructional model (and its variants) on students' science, mathematics, and motivation outcomes?

2. What is the variation in these effects? Can that variation be explained by study characteristics observed (e.g., instructional model variations, study settings, outcome subdomains)?



Eligibility Criteria

- Evaluated the 5E instructional model (or a related variant such as 3E or 7E)
- Conducted in school or lab-based setting
- Sampled students aged 4-18
- Assigned students, classrooms, or schools using random assignment
- Included a business-as-usual control group
- Measured mathematics, science, or motivation after the program concluded
- Published or produced the report/paper on or after 1990
- Wrote the report/paper in English

Methods - Protocol, Search, & Screen

- Pre-registered review protocol available on OSF (https://shorturl.at/cftuQ)
- Systematic search tailored to each database (traditional databases including dissertations and theses, non-traditional databases, research firm websites)
- Screening: Abstract and Full-Text with 2 researchers
- Used *MetaReviewer* to code study, intervention, and effect sizes

Methods – Analysis

- Estimated all effect sizes in R using *metafor*
  - Where available, prioritized effects controlling for pretest differences
  - Then, estimated difference-in-difference posttest – pretest effect size
  - Utilized the effective sample size because some studies used clustered trials but failed to account for dependency

- Meta-analysis: Random effects meta-analysis with adjustment for correlated and hierarchical effects (CHE model)
  - Determined it necessary to split the dataset by outcome type given policy-relevant decisions and ease of interpretation
  - Resulted in 3 meta-analytic models (science, math, motivation)

- Pre-analysis plan specified confirmatory and exploratory moderator analyses
  - Confirmatory = 6 variables, ran with basic ANOVA-like models
  - Exploratory = 1 additional ANOVA-like model + 3 meta-regression models
    - (1) all confirmatory and exploratory variables; (2) all conf. + exp variables including an interaction term; (3) all variables collected
    - Estimated pseudo-R-squared as well as model-fit statistics

- Conducted publication bias analyses that accounted for ES dependency
- Conducted sensitivity analyses to assess robustness of analytic decisions (not presented)

Study Characteristics (N = 61)	
Date of Publication	
Mean (SD)	2010 (5.6)
Median [Min, Max]	2010 [1990, 2020]
Peer-Review Status	
No peer-reviewed reports	16 (26%)
At least one peer-reviewed report	45 (74%)
Country	
US	9 (15%)
Turkey	29 (48%)
Other	23 (38%)
Grade Level	
K-5	11 (18%)
6-8	15 (25%)
9-12	35 (57%)
Assignment	
Individual	11 (18%)
Within School	22 (36%)
2 Schools Per Condition	16 (26%)
3 Schools Per Condition	7 (11%)
4+ Schools Per Condition	5 (8%)
Instructional Model	
3e	8 (13%)
5e	45 (74%)
7e	8 (13%)
Professional Development	
No/Not Reported	32 (52%)
Yes	29 (48%)
Intervention Duration (Weeks)	
Mean (SD)	7.7 (7.1)
Median [Min, Max]	6 [2, 36]
Missing	13 (21%)

Effect Size Characteristics (N = 156)	
Outcome Domain	
Mathematics	9 (6%)
Motivation	45 (29%)
Science	102 (65%)
Outcome Measure	
Math: General	3 (2%)
Math: Geometry	5 (3%)
Math: Measurement	1 (1%)
Motivation: Perceived Cost	3 (2%)
Motivation: Intrinsic Value	6 (4%)
Motivation: Expectancy	32 (21%)
Motivation: Utility or Attainment Value	4 (3%)
Science: Critical thinking, creativity, or process skills	11 (7%)
Science: General	12 (8%)
Science: Life Science	28 (18%)
Science: Physical Science	51 (33%)
Sample Composition: Sex	
Completely Female (100%)	16 (10%)
Mostly Female (99 – 56%)	18 (12%)
Evenly Distributed (55 – 45% Females)	51 (33%)
Mostly Male (99 – 56%)	23 (15%)
Completely Male (100%)	8 (5%)
Not Reported	40 (26%)
Sample Composition: SES	
Low SES	7 (4%)
Low-middle SES	3 (2%)
Middle SES	11 (7%)
Middle-upper SES	5 (3%)
Not Reported	130 (83%)
Outcome Reliability	
.67 - .77	63 (40%)
.78 - .89	46 (29%)
.90 - .98	16 (10%)
Not Reported	31 (20%)
Outcome Measure Developer	
Unaffiliated with Implementation	64 (41%)
Affiliated with Implementation	92 (59%)
Total Effective Sample Size	
Mean (SD)	160 (240)
Median [Min, Max]	86.0 [11, 1220]

Descriptive Results

Outcome Domain	k (m)	Average (SE)	95% CI	σ^2, τ^2	95% PI
Science	54 (102)	0.82 (0.08)	0.67, 0.97	0.20, 0.11	0.15, 1.48
Math	6 (9)	0.70 (0.20)	0.31, 1.10	0.01, 0.21	-0.19, 1.6
Motivation	21 (45)	0.24 (0.05)	0.14, 0.34	0.04, 0.01	0.24, 0.24

Notes: k = number of studies; m = number of effect sizes; SE = standard error; CI = confidence interval; σ^2 represents within-study variance; τ^2 represents between-study variance; PI = prediction interval.

Science Moderator Results: Bivariate (One-Way ANOVAs)

Moderator	Level	k (m)	Average Effect Size (SE)	Q3 -value, p-value
Instructional Model				3.74, 0.03
	3E	7 (15)	0.42 (0.15)#	
	5E	41 (74)	0.82 (0.09)	
	7E	6 (13)	1.23 (0.18)#	
Outcome Subdomain				2.2, 0.09
	Critical Thinking	5 (11)	0.67 (0.21)	
	General	6 (12)	0.39 (0.09)	
	Life Science	18 (28)	0.86 (0.14)	
	Physical Science	30 (51)	0.90 (0.11)	
Intervention Length				1.07, 0.38
	Less Than 1 Month	17 (23)	0.89 (0.14)	
	1-2 Months	18 (41)	0.95 (0.14)	
	2-3 Months	3 (5)	0.42 (0.20)	
	3-4 Months	4 (11)	0.45 (0.15)	
	5+ Months^	3 (6)	0.66 (0.33)	
	Not Reported	9 (16)	0.78 (0.21)	
Professional Development				2.33, 0.13
	Provided	27 (50)	0.71 (0.10)	
	Not Reported/Provided	27 (52)	0.94 (0.11)	
Sample: Age				2.27, 0.11
	K – 5	11 (26)	0.61 (0.14)	
	6 – 8	12 (21)	0.68 (0.18)	
	9 – 12	31 (55)	0.96 (0.10)	
Sample: Sex				2.16, 0.07
	100% Female	5 (10)	0.65 (0.07)	
	99 – 56% Female	5 (14)	0.33 (0.10)	
	55 – 45% Female	21 (34)	0.96 (0.12)	
	44 – 1% Female	7 (14)	1.06 (0.28)	
	0% Female	4 (6)	0.95 (0.15)	
	Not Reported	17 (24)	0.71 (0.11)	
Country				3.51, 0.03
	US	9 (26)	0.46 (0.13)#	
	Turkey	28 (48)	0.96 (0.11)#	
	Other	17 (28)	0.83 (0.13)	

Notes: k = number of studies; m = number of effect sizes; # indicates statistically significant differences between the levels ($p < .01$); ^ no studies reported an intervention length of 4-5 months.

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Notes:
k = number of studies, m = number of effect sizes,
Q-value represents the omnibus test of differences among the levels,
represents a statistically significant post-hoc test between the specific levels.

Moderator Results: Bivariate (One-Way ANOVAs)

Moderator	Level	k (m)	Average Effect Size (SE)	Q3 -value, p-value
Country				3.51, 0.03
	US	9 (26)	0.46 (0.13)#	
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	Other	17 (28)	0.83 (0.13)	

Notes:
k = number of studies, m = number of effect sizes,
Q-value represents the omnibus test of differences among the levels,
represents a statistically significant post-hoc test between the specific levels.

The Corpus of Studies

Variable	Level	US	Turkey	Other	χ^2, p-value	3E	5E	7E	χ^2, p-value
Sample: Age					20.34, 0.01				17.66, 0.01
	K-5	9.3	3.7	7.4		7.4	9.3	3.7	
	6-8	3.7	11.1	7.4		1.9	20.4	0	
	9-12	3.7	37	16.7		3.7	46.3	7.4	
Professional Development					13.30, 0.01				2.81. 0.25
	No/Not Reported	7.4	18.5	24.1		9.3	35.2	5.6	
	Yes	9.3	33.3	7.4		3.7	40.7	5.6	
Sample: Sex					51.66, 0.01				23.59, 0.01
	Completely Female	3.9	0.0	5.9		3.9	5.9	0	
	Mostly Female	3.9	4.9	4.9		5.9	7.8	0	
	Evenly Distributed	1.0	26.5	5.9		2	23.5	7.8	
	Mostly Male	5.9	7.8	0		1	10.8	2	
	Completely Male	0.0	0.0	5.9		1	4.9	0	
	Not Reported	10.8	7.8	4.9		1	19.6	2.9	
Assignment					13.09, 0.11				15.87, 0.04
	Individual	3.7	7.4	9.3		1.9	18.5	0	
	Within School	1.9	22.2	11.1		5.6	22.2	7.4	
	2 Schools Per Condition	5.6	13	5.6		1.9	18.5	3.7	
	3 Schools Per Condition	1.9	7.4	1.9		3.7	7.4	0	
	4+ Schools Per Condition	3.7	1.9	3.7		0	9.3	0	
Outcome Subdomain					37.45, 0.01				8.83, 0.18
	Science: Critical thinking	7.8	2	1		3.9	4.9	2	
	Science: General	4.9	0	6.9		2.9	8.8	0	
	Science: Life Science	2	12.7	12.7		2.9	21.6	2.9	
	Science: Physical Science	10.8	32.4	6.9		4.9	37.3	7.8	
Country					NA				10.35, 0.03
	US	16.7	0	0		3.7	13.0	0	
	Turkey	0	51.9	0		1.9	42.6	7.4	
	Other	0	0	31.5		7.4	20.4	3.7	

Notes: Cell values represent proportions of studies represented, except sample:sex and measure are proportion at the effect size level; NA = not applicable; χ^2 is the chi-square value for the individual table, e.g., sample:age by country.

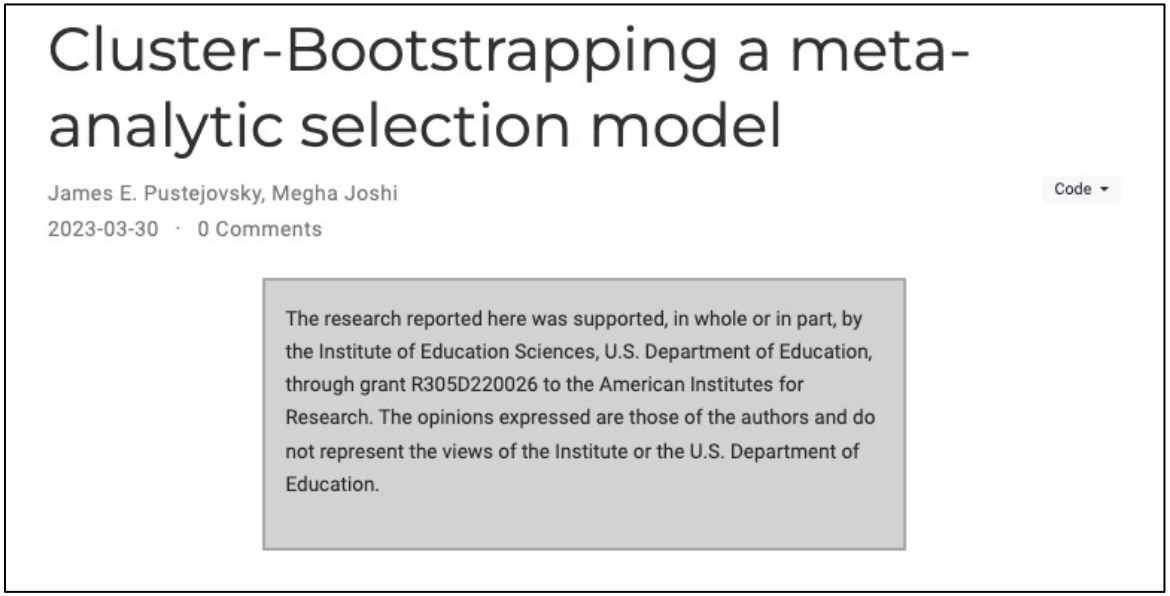
Moderator Results: Meta-Regression of "Model 1"

Variable	Reference Level	Coefficient (SE)	t-stat, df	p-value
Intercept	-	0.88 (0.27)	3.26, 13.81	0.01
Sample-Sex: 100% Female	Sample-Sex: 55 – 45% Female	-0.22 (0.21)	-1.03, 7.55	0.33
Sample-Sex: 99 – 56% Female		-0.69 (0.29)	-2.38, 8.85	0.04
Sample-Sex: 44 – 1% Female		0.13 (0.36)	0.37, 9.05	0.72
Sample-Sex: 0% Female		0.04 (0.27)	0.16, 7.20	0.87
Sample-Sex: Not Reported		-0.22 (0.15)	-1.48, 15.03	0.16
Grade Level: 6 – 8	Grade Level: K – 5	0.18 (0.24)	0.77, 10.51	0.46
Grade Level: 9 – 12		0.16 (0.29)	0.54, 11.94	0.60
Received Professional Development	Did Not Receive	-0.29 (0.20)	-1.45, 21.33	0.16
Length: 1-2 Months	Length: <1 Month	0.20 (0.20)	0.97, 17.37	0.34
Length: 2-3 Months		-0.15 (0.31)	-0.50, 4.50	0.64
Length: 3-4 Months		0.04 (0.38)	0.11, 7.52	0.92
Length: 5+ Months^		-0.33 (0.31)	-1.06, 7.60	0.32
Length: Not Reported		-0.11 (0.24)	-0.46, 16.24	0.65
Subdomain: Life Science	Subdomain: Physical	-0.12 (0.22)	-0.54, 19.29	0.60
Subdomain: General		-0.22 (0.31)	-0.72, 4.75	0.51
Subdomain: Critical Thinking		-0.29 (0.40)	-0.71, 3.92	0.52
Instructional Model: 3E	Instructional Model: 5E	-0.16 (0.24)	-0.66, 10.02	0.52
Instructional Model: 7E		0.39 (0.32)	1.21, 9.42	0.25
Country: Turkey	Country: US	0.16 (0.28)	0.58, 14.58	0.57
Country: Other		0.11 (0.23)	0.47, 14.57	0.64

Notes: Reference level is the categorical level removed from the model; coefficient is the difference in effect size between the reference level and the row variable; SE = standard error; df = degrees of freedom; ^Length: none of the studies' intervention length were between 4-5 months; *R*-squared = 36.6%.

Publication Bias: Selection Model on Science Outcome Domain

	Original Estimate	Selection-Adjusted	Bootstrapped 95% CI
Average Effect	0.82	0.82	0.63, 1.04
Tau	0.33	0.62	0.46, 0.77
Delta	NA	0.98	0.52, 1.85



https://www.jepusto.com/cluster-bootstrap-selection-model/

Discussion

- Overall positive effects
- Large differences in effectiveness across instructional models and countries
- Differences 5E/7E & 3E are consistent with *How People Learn* (NRC, 2000) as 3E neglects student preconceptions
- Some large differences shrink in the full meta-regression model, suggesting some confounding of moderator effects
- Did not find evidence of publication bias

Future Research Directions

- The corpus of studies suggest that the evidence is not distributed evenly across study characteristics. E.g., More evidence is needed:
    - From studies of K-8 students
    - From larger studies, especially for the 7E model
    - From studies using more broadly focused outcome measures
    - From studies conducted in a wider cross-section of countries (e.g., no eligible US studies of the 7E model)

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Thank you!

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