

Promoting explanation and argumentation in science instruction: Investigating supports for students and teachers

Katherine L. McNeill, Boston College, USA

Outline

- Science as a set of practices
- Explanation and Argumentation
- Project #1 – Student Scaffolds
  - Fading curricular scaffolds (McNeill et al., 2006)
  - Context-specific vs generic scaffolds. Role of teacher. (McNeill et al., 2009)
- Project #2 – Teachers' Use
  - Variation in teachers' use of curriculum and the impact on student learning (McNeill et al., 2013)
- Project #3 – Educative Curriculum
  - Designing "educative" curriculum and the impact on teachers' beliefs (Loper et al., in review; McNeill et al., in review)
- Conclusions & Future Directions

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Science Practices: A shift in science education

- Historically, science education has overemphasized students learning a myriad of facts rather than understanding how ideas are developed and transform over time (Roth & Garnier, 2006).
- Contemporary views stress the importance of knowledge in use, emphasizing that students should be able to apply science concepts in diverse contexts as they engage in practices (Duschl, Schweingruber & Shouse, 2007).

Science Practices: What are they?

NEXT GENERATION SCIENCE STANDARDS For States, By States

- "Science is not just a body of knowledge that reflects current understanding of the world; it is also a set of practices used to establish, extend, and refine that knowledge. Both elements – knowledge and practice – are essential" (NRC, 2012, p. 26).
- Eight Science Practices
  1. Asking questions and defining problems
  2. Developing and using models
  3. Planning and carrying out investigations
  4. Analyzing and interpreting data
  5. Using mathematics and computational thinking
  6. Constructing explanations and designing solutions
  7. Engaging in argument from evidence
  8. Obtaining, evaluating, and communicating information

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Importance of Explanation & Argumentation

- Science is is about constructing arguments and considering and debating multiple explanations for phenomena (Osborne, Erduran, & Simon, 2004).
- Engaging students in explanation and argumentation can:
  - Increase student ability to construct explanations and arguments (Yerrick, 2000).
  - Foster deeper understanding of important science concepts (Zohar & Nemet, 2002).
  - Change students' image of science (Bell & Linn, 2000).

Challenges with Explanation & Argumentation

- Argumentation is frequently left out of classroom practice (Kuhn, 1993).
  - Students are rarely in positions to substantively engage with one another's ideas (Lemke, 1990; Hogan & Corey, 2001).
- Students can have difficulty engaging in argumentation.
  - Difficulty using appropriate (Sandoval, 2003) or sufficient (Sandoval & Millwood, 2005) evidence.
  - Difficulty providing backing or reasoning for why evidence supports the claim (Bell & Linn, 2000).
  - Difficulty supporting or refuting the ideas of their peers (McNeill & Pimentel, 2010).

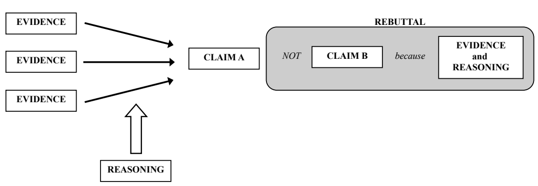
Defining Explanation and Argumentation

- Explanation
  - *make sense* of how or why a phenomenon occurred
  - Examples:
    - Explain why the biodiversity decreased
    - Explain why a car rolled farther
- Argumentation:
  - *defend* knowledge claims through persuasive discourse in which there are *multiple claims*
  - Examples:
    - Argue for your explanation
    - Argue for your experimental design
    - Argue for your model

CER Framework *(McNeill & Krajcik, 2012)*

- **Claim**
  - a conclusion about a problem
- **Evidence**
  - scientific data that supports the claim
- **Reasoning**
  - a justification that shows why the data counts as evidence to support the claim and includes appropriate scientific principles
- **Rebuttal**
  - describes alternative explanations and provides counter evidence and reasoning for why the alternative is not appropriate.

CER Framework (McNeill & Krajcik, 2012)



Chemistry Example

Are any of the liquids the same substance?

Liquids 1 and 4 are the same substance. (Claim) They both have a density of .93 g/ cm^3, have no color, and start to melt at -98 C. (Evidence) For substances to be the same, they must have the same properties. Since Liquids 1 and 4 have the same properties, they are the same substance. The other 2 liquids are different substances because they have different properties. (Reasoning)

Physics Example

Does mass affect how quickly an object falls?

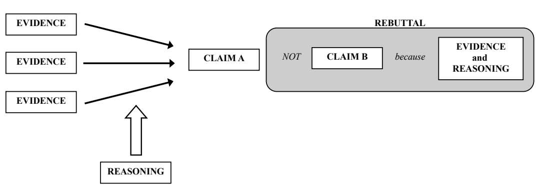
No, mass does not affect how quickly an object falls. (Claim) In the investigation, the blocks had different masses – 20 g., 30 g., 44 g., 123 g and 142 g. But the average time for all five blocks was about the same - between 1.5 and 1.8 seconds. (Evidence) Since the blocks had different masses but took about the same time to fall, I know that mass does not affect how quickly something falls. (Reasoning)

Biology Example

What will happen to the shark population if the phytoplankton populations die out?

The shark population will die out.(Claim) The shark eats other fish such as the ocean fish and the lantern fish. The ocean fish and the lantern fish eat other organisms such as shrimp and copepods. The shrimp and copepods eat the phytoplankton. (Evidence) Phytoplankton are producers and they make their own food from the sun. All of the other organisms in the food web depend on the phytoplankton, even if they do not directly eat them. If the phytoplankton die, primary consumers (shrimp and copepods) will die because they will have no food which will cause the secondary consumers (ocean fish and lantern fish) to die, which will cause the shark to die. (Reasoning) You might think the shark population would not change, because they do not eat the phytoplankton. But they will actually die out because they eat organisms that eat organisms that eat the phytoplankton. (Rebuttal)

CER Framework (McNeill & Krajcik, 2012)



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Project #1: Instructional Context

- These study took place during an eight-week standards-based chemistry curriculum designed for 7th grade students (12-13 years-old).
- The unit includes three key content learning goals:
  - Substances & Properties
  - Chemical Reactions
  - Conservation of Mass

Project 1A - Fading Curricular Supports: Study Design (McNeill et al., 2006)

- Students received one of two types of curricular supports
  - Continuous: Detailed written supports throughout
  - Faded: Less detailed written supports over time (scaffolds)
- Randomly assigned classes of students to the Continuous and Faded groups so that teachers with multiple classes taught both groups

Project 1A - Fading Curricular Supports
Study Design

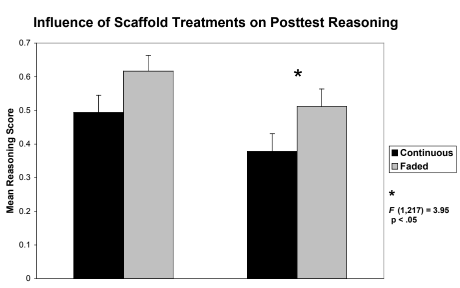
Stage	Faded Scaffold
Stage I	**Claim** (Write a sentence that states whether the nail and wrench are the same or different substances.) **Two Pieces of Evidence** (Provide two pieces of data that support your claim that the nail and the wrench are the same or different substances.) **Evidence #1** **Evidence #2** **Reasoning** (Write a statement that connects your evidence to your claim that the nail and the wrench are the same or different substances.)
Stage II	**Claim** (Write a sentence that answers the question.) **Evidence** (Provide data that support your claim.) **Reasoning** (Connect evidence to claim.)
Stage III	Remember to include claim, evidence, and reasoning.

Project 1A - Fading Curricular Supports
Participants and Scoring

Site	Urban A	Town B	Total
Schools	3	1	4
Teachers	3	3	6
Classrooms	9	5	14
Students	260	71	331

- Students completed identical pre- and posttest measures.
- 30 multiple-choice items (i.e. defining and identifying items)
- 4 CER open-ended items.
  - Two items had detailed Continuous-type supports. Two items had no supports.
  - Independent raters scored the items. Inter-rater reliability was 96% for claim, 88% for evidence, and 85% for reasoning.

Project 1A - Fading Curricular Supports
Results



Project 1A - Fading Curricular Supports Results

- Students had the most difficulty with the reasoning component of CER throughout the unit.
- Students had the most difficulty with reasoning on the posttest (Claim = 3.20, Evidence = 2.73, and Reasoning = 1.76).
- Classroom discussions also reflect this student difficulty with reasoning.

Results: Student Discussion of Reasoning

Project 1A - Fading Curricular Supports Conclusions

- Fading CER scaffolds better prepared students to write explanations.
- Fading scaffolds may have had the strongest effect on reasoning because this was the most difficult component for students.
  - May have forced students to revisit this question of "What is the reasoning?"
- However, this also suggested that other supports might better prepare students.

Project 1B – Scaffolds & Teacher: Study Design (McNeill et al., 2009)

- Two versions of the student books:
  - Context-Specific: provide students with hints about the task and content knowledge
  - Generic: help students understand a general framework for explanation
- Randomly assigned classes to context-specific or generic treatments.
- Videotaped 3 lessons for each teacher.

Project 1B – Scaffolds & Teacher: Study Design - Scaffolds

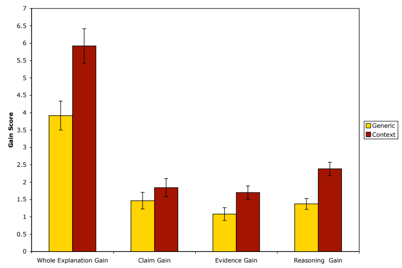
Context Specific Scaffold	Generic CER Scaffold
(State whether the stones in Ring #1 and Ring #2 are the same substance. Provide whether properties, such as density, melting point, and color, are the same or different. Do not include measurements that are not properties, such as mass and volume. Tell why properties being the same or different tells you whether two stones are the same substance.)	**Claim** (Write a statement that responds to the original problem.) **Evidence** (Provide scientific data to support your claim. You should only use appropriate data and include enough data. Appropriate data is relevant for the problem and allows you to figure out your claim. Remember that not all data is appropriate. Enough data refers to providing the pieces of data necessary to convince someone of your claim.) **Reasoning** (In your reasoning statement, connect your claim and evidence to show how your data links to your claim. Also, tell why your data count as evidence to support your claim by using scientific principles. Remember reasoning is the process where you apply your science knowledge to solve a problem.)

Project 1B – Scaffolds & Teacher: Participants and Scoring

Teacher	Type of School	Number of 7th Grade Classes	Total Number of Students
Ms. Kittle	Urban Public	5	164
Ms. Marshall	Urban Public	5	162
Ms. Hill	Urban Public	2	66
Mr. Kaplan	Urban Public	4	71
Ms. Foster	Urban Charter	2	49
Ms. Nelson	College Town Independent	4	56
Total		22	568

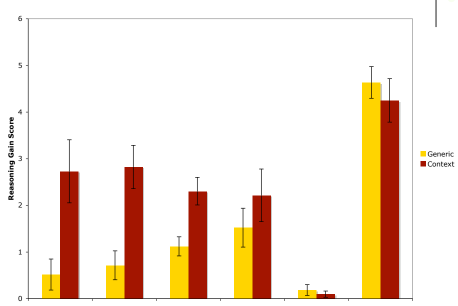
- Identical pre- and posttest measures:
  - 15 multiple-choice items (i.e. defining and identifying items)
  - Three open-ended CER explanation items. Inter-rater reliability was greater than 98% for claim, 94% for evidence, and 98% for reasoning.

Project 1B – Scaffolds & Teacher: Results - Curricular Scaffolds



- Context-specific scaffolds resulted in greater student learning for the whole explanation, evidence & reasoning.
- Context-specific also resulted in greater student learning for the multiple-choice, F (1, 324) = 3.97, $p < .05$.

Project 1B – Scaffolds & Teacher: Results - Scaffolds and Teacher



Project 1B – Scaffolds & Teacher: Results: Summary

- Mr. Kaplan, Ms. Hill & Ms. Kittle
  - Context-specific resulted in greater student learning in terms of writing scientific explanations compared to generic scaffolds
  - Qualitative case studies suggested that all 3 teachers explicitly defined CER and it impacted their other instructional strategies.
- Ms. Marshall, Ms. Foster & Ms. Nelson
  - No significant curricular effect

Project 1B – Scaffolds & Teacher: Conclusions

- The effect of written curricular scaffolds depends on the teacher's enactment of the curriculum.
  - Context-specific curricular scaffolds were more effective only in classrooms where teachers provided the general CER framework
- Synergy
  - "…for productive synergy to occur…different materials need to share semiotic features, and these features need to be consistent not only with the designers' but with the teacher's conception of the task, goals, and discipline" (Tabak, 2004).

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Project #2 – Teachers' Use: Instructional Context (McNeill et al. 2013)

- This study took place during an urban ecology curriculum, *Urban EcoLab: How can we develop healthy cities?*
  - Developed as a capstone course for high school students (i.e. 11th and 12th graders).
  - Consisted of eight modules each of which is designed to last between two and four weeks.

Project #2 – Teachers' Use: Study Design

- We conducted a quasi-experimental design with student pre- and post-tests to capitalize on the natural variation in teacher instruction (Shadish, Cook & Campbell, 2002).
- Data sources included:
  - Teacher pre-survey (background and instructional practices)
  - Teacher lesson enactment surveys (completion, adaptation & activity structure – individual, group, lecture, discussion)
  - Student pre- and post- assessments
    - 21 multiple-choice items (i.e. identifying and defining)
    - 4 open-ended items (focused on science practices – including CER)
- We used hierarchical linear modeling (HLM)
  - Students are nested within teachers' classrooms as such multi-level modeling provides a more accurate estimation of effects and variance (Raudenbush & Bryk, 2001).

Project #2 – Teachers' Use: Participants


Table: Teacher Descriptive Statistics (n = 22)

Years of Experience	1-5	6-10	11-15	16-20	21-25	26-30
# of teachers	8	6	3	3	1	1

Highest Degree obtained in Science	N.A.	Bachelors	Masters	Doctorate
# of Teachers	1	14	6	1

Highest Degree obtained in Education	N.A./ Associate	Bachelors	Masters	Doctorate
# of Teachers	3	5	14	0

- The participants in this study included 22 teachers from 21 different schools piloting the urban ecology curriculum and their 935 students.
- Their schools were located in three regions of the United States: Northeast, Midwest, and Southwest.

Project #2 – Teachers' Use: Results - FUM

Table: Fully Unconditional Model

	Multiple-Choice Assessment	Open-Ended Assessment
Tau (τ_{FUM})	2.575	12.168
Sigma-squared (σ^2_{FUM})	5.973	18.959
Lambda-reliability (λ)	0.820	0.868
Intraclass Correlation (ICC)[a]	0.301	0.391
Adjusted-ICC[b]	0.345	0.425

[a] ICC = $\tau/(\tau + \sigma^2_{FUM})$
[b] Adjusted ICC = $\tau/(\tau + (\lambda\sigma^2_{FUM})$

- 34.5% of the variance in student achievement on the multiple-choice assessment existed between teachers.
- 42.5% of the variance in student achievement on the open-ended assessment existed between teachers.

Project #2 – Teachers' Use: Results – Between-Teacher Model

Table: Between-Teacher HLM Model

	Multiple-Choice Assessment	Open-Ended Assessment
Random Effects		
Intercept (β_0)		
Percentage of Time Teacher Lectured	-5.146*	---
Level of Adaptation	---	-5.994*
Frequency of Argument	---	0.947~
Variance Components for Random Effects		
Intercept Variance ($\tau_{between}$)	1.987***	7.438***
Proportion of Variance Explained[a]	0.255	0.328

~p < .10; * p < .05; ** p < .01; *** p < .001
[a]Between Proportion of variance explained = $(\tau_{withinmodel} - \tau_{betweenmodel})/\tau_{withinmodel}$

- Multiple-choice: 1) percentage of time spent on group work and 2) percentage of time spent lecturing.
- Open-Ended: 1) average level of adaptation and 2) frequency students engage in argument

Project #2 – Teachers' Use: Conclusions

- Between 34% and 42.5% of the variation in student achievement was a result of how the teachers used the curriculum materials in their classrooms.
- Teachers who spent a greater percentage of time on group work, a greater percentage of time on having students engage in argument, and a smaller percentage of time on lecture had students with greater science learning gains.
- Teachers who reported adapting the curriculum more had lower student learning in terms of the science practices.

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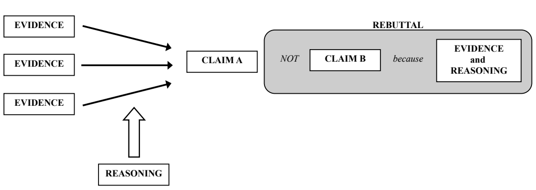
Project #3 – Educative Curriculum: Instructional Context (McNeill et al., in review)

- These study took place during an twelve-week standards-based Earth & Space science unit designed for middle school students (11 – 14 year-olds).
- The curriculum includes three units:
  - Rocks
  - Currents
  - Space

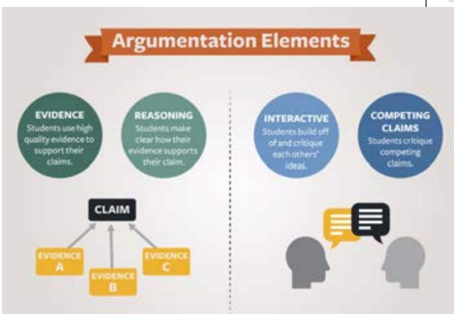
Project #3 – Educative Curriculum: Theoretical Background

- Teachers enact curriculum in different ways, which impacts student learning (McNeill et al., 2013)
- Teachers can have different views and understandings of argumentation (McNeill & Knight, 2013).
- Educative (i.e. support teacher learning) curriculum materials offer one potential avenue for supporting students in science practices (Davis & Krajcik, 2005; Davis, et. al, 2014).

Project #3 – Educative Curriculum: CER Framework (McNeill & Krajcik, 2012)



Project #3 – Educative Curriculum Four Conceptions (McNeill et al., 2016)



Project #3 – Educative Curriculum

Rocks Introduction

Argumentation Toolkit Overview

Project #3 – Educative Curriculum: Study Design

Randomized Experimental (n=90 teachers)

- All teachers received a digital teacher's guide and all student materials
- Treatment teachers received additional MECMs (videos, interactive elements)
- No requirements: use materials as you would normally use them.
- Data Collection
  - Back-end data collection on teachers' use of digital curriculum and access of videos.
  - Pre- and post-survey: PCK for argumentation, Beliefs about argumentation and Curriculum Use

Project #3 – Educative Curriculum: Participants

Table: Teacher Background Information (n = 90)

	MECM Treatment (n = 46)	Control (n = 44)
Years Teaching Science		
• 0-2 years	6	6
• 3-5 years	9	8
• 6-10 years	12	14
• 11-15 years	8	9
• 16+ years	11	7
Highest Level of Science Education		
• No Response	4	1
• Bachelors Degree	38	31
• Masters Degree	3	12
• Doctorate Degree	1	0
Highest Level of Education		
• No Response	1	1
• Bachelors Degree + teaching certificate	26	14
• Masters Degree	18	29
• Doctorate Degree	1	0

Project #3 – Educative Curriculum: Belief Scales

Table: Teacher Beliefs about Scientific Argumentation.

Sub-Scale	Number of Items	Sample Item	Cronbach's Alpha Pre	Cronbach's Alpha Post
Teacher Self-Efficacy[a]	8	I feel confident facilitating students' critiques of arguments.	0.93	0.88
Learning Goals[a]	7	Engaging students in argumentation is an important part of learning science.	0.87	0.77

[a] Response options: 1 = Strongly disagree, 2 = Disagree, 3 = Agree, 4 = Strongly Agree
[b] Response options: 1 = Not capable, 2 = Somewhat capable, 3 = Capable, 4 = Very Capable

Project #3 – Educative Curriculum: Results – Teacher Beliefs

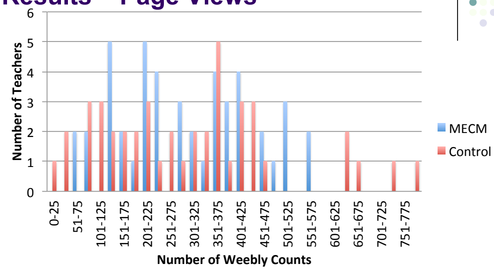
Table: Changes in Teacher's Beliefs about Argumentation

	N	Pretest Mean (se)	Pretest SD	Posttest Mean (se)	Posttest SD	Paired Samples t-test	Sig.†
Self Efficacy	90	3.09(.05)	0.52	3.51(.04)	0.38	-8.31	<.001
Learning Goals	90	3.60(.04)	0.39	3.82(.04)	0.25	-5.59	<.001

† A Bonferonni adjustment was applied to account for multiple tests (α/3 = 0.017)

- The results indicate that all teachers' posttest beliefs were significantly higher than teachers' pretest belief scores.

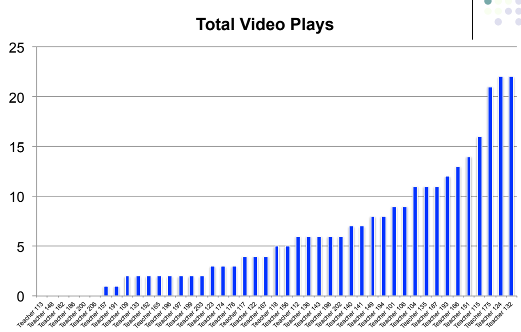
Project #3 – Educative Curriculum: Results – Page Views



MECM (n = 46):
Average count ~ 299
Range: 62 to 576

Control (n = 44):
Average count ~ 304
Range: 14 to 799

Project #3 – Educative Curriculum: Results – Video Plays



Project #3 – Educative Curriculum: Results – Regression

Table: Teacher Self Efficacy Regression Models for Scientific Argumentation

	Model 1 Demographics	Model 2 Condition	Model 3 Backend Use	Model 4 Self-Report Use
	Coeff (s.e.)	Coeff (s.e.)	Coeff (s.e.)	Coeff (s.e.)
Intercept	2.44(0.24)***	2.50(0.22)***	2.38(0.23)***	2.15(0.33)***
Teacher Background				
Pre Belief Survey	0.36(0.07)***	0.35(0.07)***	0.36(0.07)***	0.35(0.07)***
Years Teaching	-0.02(0.03)			
Degree	0.08(0.08)			
Race	-0.13(0.10)			
Gender	-0.01(0.07)			
Condition				
Group		-0.13(0.07)	-0.09(0.08)	**-0.14(0.07)***
Backend Curriculum Use				
Total Page Views†			<0.01(<0.01)	
Total Video Views			-0.01(0.01)	
Self-report Curriculum Use				
# Lessons Taught†				**0.07(0.03)***
Percentage Modified				-0.23(0.14)
Comfort with Digital				-0.02(0.05)
Way Used Curriculum				0.03(0.04)
Adjusted R^2	22.0%	24.9%	25.8%	29.9%

**** Significant at $p < .001$, ** Significant at $p < .01$, * Significant at $p < .05$
† Variable rescaled to represent a change of 10 units.

Project #3 – Educative Curriculum: Results – Regression

Table: Teacher Learning Goals Regression Model for Scientific Argumentation

	Model 1	Model 2	Model 3	Model 4
	Coeff (s.e.)	Coeff (s.e.)	Coeff (s.e.)	Coeff (s.e.)
Intercept	2.89(0.24)***	2.94(0.23)***	2.91(0.23)***	2.69(0.29)***
Teacher Background				
Pre Belief Survey	0.25(0.06) ***	0.24(0.06)***	0.24(0.06)***	0.23(0.06)***
Years Teaching	0.02(0.02)			
Degree	-0.05(0.05)			
Race	0.01(0.07)			
Gender	<0.01(0.05)			
Condition				
Group		0.02(0.05)	0.01(0.06)	0.02(0.05)
Backend Curriculum Use				
Total Page Views†			<0.01(<0.01)	
Total Video Views			<0.01(0.01)	
Self-report Curriculum Use				
# Lessons Taught†				0.06(<0.02)*
Percentage Modified				-0.14(0.10)
Comfort with Digital Curriculum				<0.01(0.03)
Way Used Curriculum				0.02(0.03)
Adjusted R^2	12.7%	12.8%	12.5%	18.7%

**** Significant at p < .001, ** Significant at p < .01, * Significant at p < .05
† Variable rescaled to represent a change of 10 units.

Project #3 – Educative Curriculum: Conclusions

- Enacting a educative curriculum can support positive changes in teachers' beliefs about argumentation.
- There was a wide range in how teachers used the digital curriculum.
- Teachers became more confident in their ability to teach argumentation as they enacted more lessons. However, the increase in self-efficacy was lower for the teachers receiving the MECM treatment.
- One potential reason for this is the videos may have *problematized* (Reiser, 2004) what teachers thought counted as argumentation, and their role as a teacher.

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  - Designing "educative" curriculum and the impact on teachers' beliefs (Loper et al., in review; McNeill et al., in review)
- Conclusions & Future Directions

Powerpoint – www.katherinelmcneill.com (Presentations)

Conclusions Across Projects

- Curricular scaffolds can support student learning of science practices, such as explanation and argumentation.
- However, teachers enact curriculum in many different ways, which impacts student learning.
- The role of the teacher is essential in supporting students in explanation and argumentation.
- Multimedia educative curriculum materials (MECMs) serve as one potential resource to support teachers' beliefs (and potentially PCK) around explanation and argumentation.

Future Directions

- Multimedia Educative Curriculum Materials (MECM)
  - How do we support teachers' use of the curriculum to target teacher learning (in addition to teacher learning)?
  - Are there ways to make the MECMs more interactive and customized for teachers' needs?
- Measuring PCK of science practices
  - How do we develop scalable assessments that take into consideration how to manifest PCK in action in a particular context?
- Supporting students in using and making sense of "Evidence"
  - How do we design in person and digital resources to support students in using and making sense of evidence?

Contact Information

- Kate McNeill
  - e-mail – kmcneill@bc.edu
  - website – www.katherinemcneill.com
  - Argumentation videos are at - www.argumentationtoolkit.org

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  - *MECM - Constructing and Critiquing Arguments in Middle School Science Classrooms,* DRL-1119584

REMOVED Slides

Context-Specific & Role of Teacher: Teacher Instructional Practices

- Videotape the same three lessons for each teacher
  - Substance and properties (focal lesson - 2 days), chemical reactions (2 days), and conservation of mass (1 day)
- Coded for instructional practices
  - Defining or making the framework explicit
  - Modeling scientific explanations
  - Discussing the rationale behind explanation
  - Connecting to everyday
  - Assessing or providing feedback
  - Connecting to prior knowledge
  - Discussing science content (accuracy and completeness)
  - Structure of classroom discourse (IRE vs. Dialogic)
- Independent raters scored the videos. Inter-rater reliability was 88%.

PCK Assessment (McNeill et al, 2016)

After writing arguments, Ms. Strong's students engage in the science seminar. During the discussion the following exchange takes place:

Alex: "I think we could live on Mars. It would be awesome!"
Melanie: "My claim is the opposite of Alex's. I don't think that humans could live on Mars."
Alex: "Why not? What's your evidence?"
Melanie: "Well there aren't any bodies of water on Mars' surface and humans need water to live."
Tina: "There might not be lakes and oceans on Mars like there are here on Earth, but I still agree with Alex because NASA scientists saw frozen water on Mars so humans could use that to live."
Melanie: "Yeah, but how much water did they find? Did they measure how much there is?"

What could have Ms. Strong said before beginning this science seminar to encourage Melanie, Alex and Tina to have this type of discussion?

a. **"The purpose behind a science seminar is for everyone to share their ideas."**
b. **"The objective of a scientific argument is to use all the evidence in the data table."**
c. **"The point of this seminar is to make sure we all understand your argument."**
d. **"The goal of argumentation is to convince each other of the strength of a claim."**

PCK Assessment (McNeill et al, 2016)

- PCK needs to be treated not as information, but considered in terms of how it manifests itself in action in a particular context (Settlage, 2013).
- Conceptualization of PCK of argumentation
  - Moving beyond pseudoargumentation of surface level features to target quality of argumentation
  - Focus on dialogic argumentation needs to focus on students building off of and critiquing each others' claims.
- PCK assessments
  - Should use classroom contexts (e.g. vignettes, student writing and video)
  - The student argumentation examples need to highlight one specific strength or challenge