

Scientific explanation and argumentation:
Supporting claims with evidence and reasoning

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Overview of Talk

- Importance of Scientific Explanation & Argumentation
- Study #1 - Synergy between teacher practices and curricular scaffolds to support middle school students in writing arguments to explain phenomena
- Study #2 - Scientific discourse in three urban classrooms: The role of teacher in engaging high school students in argumentation
- Learning Progression for Argumentation
- Conclusions Across Studies

Why is this important?

- Science is is about constructing arguments and considering and debating multiple explanations for phenomena (Osborne, Erduran, & Simon, 2004).
- Science education should support students' development toward competent participation in a science infused world (McGinn & Roth, 1999).
- A new vision for proficiency in science - Students should generate and evaluate scientific evidence and explanations (Duschl et al., 2006).
- 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).

Why is this Hard?

- Argumentation is frequently left out of classroom practice (Kuhn, 1993).
- Classroom practices often inhibit student argumentation
  - Students are rarely in positions to substantively engage with one another's ideas (Lemke, 1990; Hogan & Corey, 2001).
  - Authoritative discourse can devalue student thinking (Tabak & Baumgartner, 2004).
- Students have difficulty articulating and justifying their claims (Sadler, 2004).
  - 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).

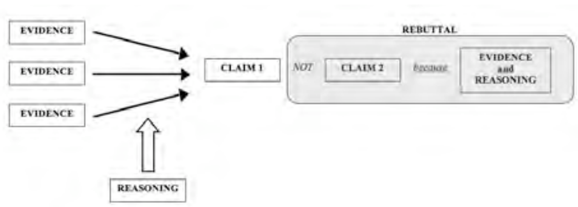
What are Explanation and Argumentation?

- Explanation
  - *make sense* of how or why a phenomenon occurred
  - Examples:
    - Explain why the biodiversity decreased
    - Explain what has happened to the pitch of bird song in cities
- Argumentation:
  - *defend* knowledge claims through persuasive discourse
  - Examples:
    - Argue for your explanation for why the biodiversity decreased
    - Argue for your experimental design to study what is happening to the biodiversity
    - Argue for your management plan to increase the biodiversity

Framework *Adapted from Toulmin (1958)*

- **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.

Framework *Adapted from Toulmin (1958)*



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)

Earth Science Example

How was the Grand Canyon formed?

The Grand Canyon was mainly formed by water cutting into and eroding the soil. (Claim) The soil in the Grand Canyon is hard, cannot absorb water and has few plants to hold it in place. When it rains in the Grand Canyon it can rain very hard and cause flash floods. The flash floods come down the side of the Grand Canyon and into the Colorado River. (Evidence) Water moving can cause erosion. Erosion is the movement of materials on the earth surface. In terms of the Grand Canyon, the water moved the soil and rock from the sides of the Grand Canyon into the Colorado River where it was then washed away.(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)

Base Rubric

Component	Level		
	0	Varies from 1-4	
Claim A statement that answers the original question/problem.	Does not make a claim, or makes an inaccurate claim.	Makes an accurate but incomplete claim.	Makes an accurate and complete claim.
Evidence Scientific data that supports the claim.	Does not provide evidence, or only provides inappropriate evidence (Evidence that does not support claim).	Provides appropriate, but insufficient evidence to support claim. May include some inappropriate evidence.	Provides appropriate and sufficient evidence to support claim.
Reasoning Using *scientific principles* to show *why data count as evidence* to support the claim.	Does not provide reasoning, or only provides reasoning that does not link evidence to the claim.	Provides reasoning that links the claim and evidence. May include some scientific principles, but not sufficient.	Provides reasoning that links evidence to claim. Includes appropriate and sufficient scientific principles.
Rebuttal Recognizes alternative explanations, and provides counter evidence and reasoning for why the alternative explanation is not appropriate.	Does not recognize that alternative explanation exists and does not provide a rebuttal or makes an inaccurate rebuttal.	Recognizes alternative explanations and provides appropriate but insufficient counter evidence and reasoning in making a rebuttal.	Recognizes alternative explanations and provides appropriate and sufficient counter evidence and reasoning when making rebuttals.

Study #1: Synergy (McNeill & Krajcik, 2009) Conceptual Framework

- *Synergistic* supports - multiple co-occurring and interacting supports (Tabak, 2004).
- Curricular Scaffolds
  - Temporary supporting structures provided by people or tools to promote learning of complex problem solving.
  - Knowledge of content and inquiry are important to engage in an inquiry practice (Gotwals & Songer, 2006).
  - Relative importance of context-specific knowledge compared to more general knowledge of inquiry (Stevens, et al., 2005).
- Teacher Instructional Practices
  - Teachers draw on their own resources and capacities to adapt curriculum materials (Remillard, 2005).
  - The role of the teacher is important for the successful use of a scaffolded tool (Pea, 2004).

Synergy: Research Questions

- How do the written scaffold treatments (context specific vs. generic) influence student learning of scientific explanations?
- How do teacher instructional practices during the unit influence student learning of scientific explanations?
- Is there an interaction between the written scaffolds and the teacher practices in promoting student learning?

Synergy: Instructional Context

- These study took place during an eight-week standards-based chemistry curriculum designed for seventh grade students.
- The unit includes three key content learning goals:
  - Substances & Properties
  - Chemical Reactions
  - Conservation of Mass

Synergy: Study Design - Scaffolds

- 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.

Synergy:
Study Design - Scaffolds

Context Specific Scaffold	Generic Explanation 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.)

Synergy:
Participants and Scoring

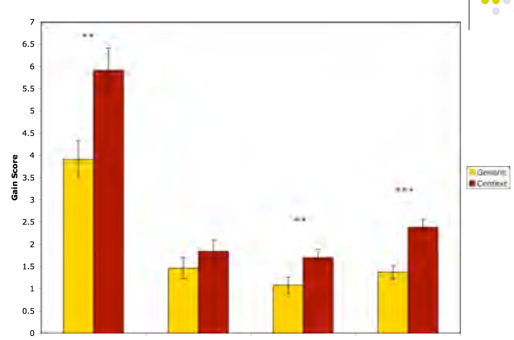
Teacher	Type of School	Number of 7th Grade Classes	Total Number of Students
Ms. Kittle	Urban Public	5	164
Ms. Marshall	Urban Public	5	162
Ms. Hill	Urban Public	2	66
Mr. Kaplan	Urban Public	4	71
Ms. Foster	Urban Charter	2	49
Ms. Nelson	College Town Independent	4	56
Total		22	568

- Identical pre- and posttest measures - three open-ended explanation items. Inter-rater reliability was greater than 98% for claim, 94% for evidence, and 98% for reasoning.

Synergy:
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%.

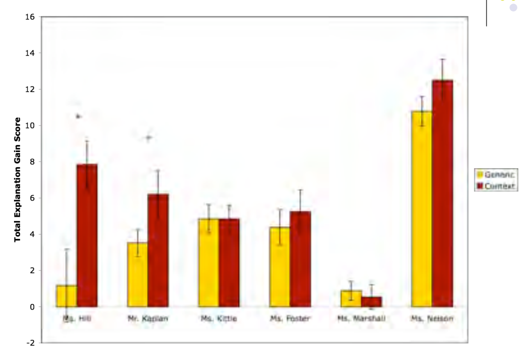
Synergy Results:
Effect of Curricular Scaffolds



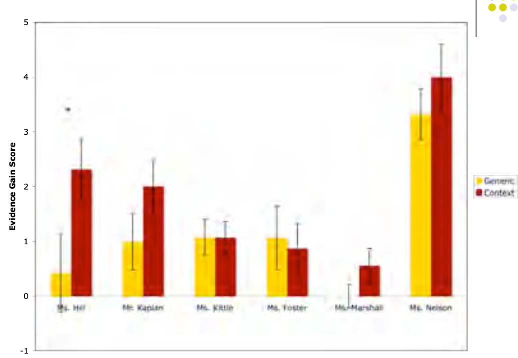
Synergy Results:
Teacher Instructional Practices

1. Framework for scientific explanation
   - Framework for scientific explanation influenced other instructional practices (e.g. connecting to everyday, feedback, modeling).
   - Aligned with curriculum materials
     - Mr. Kaplan, Ms. Hill, Ms. Kittle, and Ms. Nelson ⇨
   - Modified definition of scientific explanation - claim, definition, evidence, therefore/conclusion
     - Ms. Marshall and Ms. Foster ⇨
2. Classroom discourse
   - Traditional IRE structure
     - Mr. Kaplan, Ms. Hill, Ms. Kittle, Ms. Marshall and Ms. Foster
   - Dialogic - Greater student interaction, ownership and peer support in the classroom discussion
     - Ms. Nelson ⇨

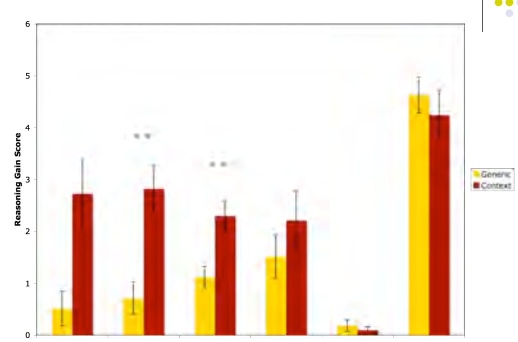
Synergy Results: Relationship between Scaffolds and Teacher - Total



Synergy Results: Relationship between Scaffolds and Teacher - Evidence



Synergy Results: Relationship between Scaffolds and Teacher - Reasoning



Synergy 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
- Ms. Marshall, Ms. Foster & Ms. Nelson
  - No significant curricular effect

Synergy: Conclusions

- Mr. Kaplan, Ms. Hill & Ms. Kittle
  - Context-specific curricular scaffolds were more effective only in classrooms where teachers provided the general explanation framework
  - "intimate intermingling of generality and context-specificity in instruction" (Perkins & Salomon, 1989).
- Ms.Marshall and Ms. Foster
  - "…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).
- Ms. Nelson
  - Curricular scaffolds may have been "redundant"

Study #2: Discourse (McNeill & Pimentel, 2010) Conceptual Framework

- Linguistic practices in classrooms define science through the ways that science is spoken and written in different contexts (Kelly, 2005).
- Traditionally, the discourse in science classrooms has been dominated by teacher talk (Crawford, 2005).
- Classroom science also often portrays science as a static set of facts than than the social construction of knowledge (Lemke, 1990).

Study #2: Discourse (McNeill & Pimentel, 2010) Conceptual Framework

- Similar to Jiménez-Aleixandre and Erduran (2008), we define argumentation in terms of two aspects.
- Argument Structure (Individual)
  - A justification of knowledge claims using reasoning and empirical evidence.
  - One individual can construct a scientific argument in their mind, on paper or in talk.
- Dialogic Interaction (Social)
  - Justifying or defending a standpoint for an audience.
  - Dialogic interaction between two or more individuals in which comments are informed by and inform previous contributions.

Discourse: Research Questions

- What are the patterns in classroom discourse in three urban science classrooms?
- What is the role of the teacher in promoting argumentation in terms of both the argument structure and dialogic interactions in classroom discourse?

Discourse: Instructional Context

- This study took place during a high school urban ecology curriculum, *How do we develop healthy and sustainable 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.
- The study occurred during Module 2, which focused on global climate change.

Instructional Context

- During Lesson 1 of Module 2, students observed two short video clips
  - Videoclip #1 - Argued Climate is Changing
  - Videoclip #2 - Argued Climate is Not Changing
- Students wrote scientific arguments.
  - “Write an argument for whether or not the earth’s climate is changing. Is global warming occurring? Provide evidence for your claim and provide your reasoning for why that evidence supports the claim.”
- Class discussed their different views on climate change.

Discourse: Participants

- Three teachers and their high school students, all from the same large urban area.

Teacher	# students in focus class	# students in school	Student Ethnicity	School Statistics
Mr. Dodson	26	261	61.7% Black 32.6 % Hispanic 2.7% White 2.3% Asian 0.8% Native American	4.9% student mobility 7.1% annual student dropout rate 57.6% graduate in 4 years
Ms. Baker	14	289	46.7% Black 33.9% Hispanic 15.9% White 3.1% Asian 0.3% Native American	21.2% mobility 4.6% annual student dropout rate 44.4% graduate in 4 years
Ms. Stevens	30	305	60.7% Black 33.8% Hispanic 3.9% White 0.3% Asian 1.3% Native American	32.5% student mobility 15.2% annual dropout rate 26.8% graduate in 4 years

Discourse: Methods

- Lesson 1 was videotaped and the classroom discussions were transcribed.
- Each transcription was broken into utterances
  - An utterance represented a unique idea or contribution to the discussion.
- Each utterance was identified as teacher or student and coded using 3 coding schemes.
  - Argument Structure
  - Dialogic Interactions
  - Teachers' Questions
- Two independent raters coded the transcripts.
  - Percent agreement was 78% for structure codes, 78% for dialogic codes and 75% for teachers' questions.

Discourse: Methods - Argument Structure

Code	Description
Claim	Conclusion about whether climate change is occurring.
Evidence	Data either in support or against climate change. The data could include a range of information from scientific data to personal experience.
Reasoning	Justification for why the evidence supports the claim. A theory (either personal or scientific) that suggests the climate is changing or is not changing.
Question	Question about the discussion
Other	All other utterances not included in the four previous codes for argument structure and question (e.g. management or not related to climate change).

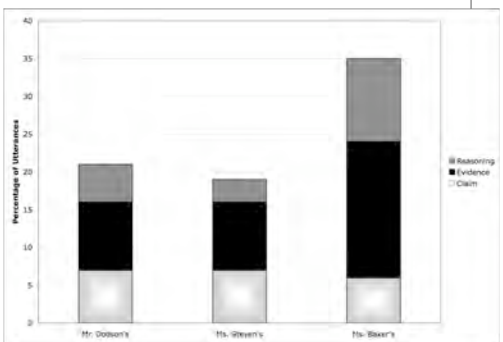
Discourse: Methods - Dialogic Interactions

Code	Description
Independent	Not linked to a previous idea offered in the discussion. It is still considered independent if the utterance is in response to a question, as long as that question is not linked to any previous ideas.
Connected	Dialogic interactions that support, refute, restate or ask a clarifying question about a previous idea
Dismissal	Explicitly or implicitly suggests that a previous contribution is not important or relevant for the discussion
Acknowledgement	Recognize a statement, but not to the extent of supporting, refuting, restating or clarifying

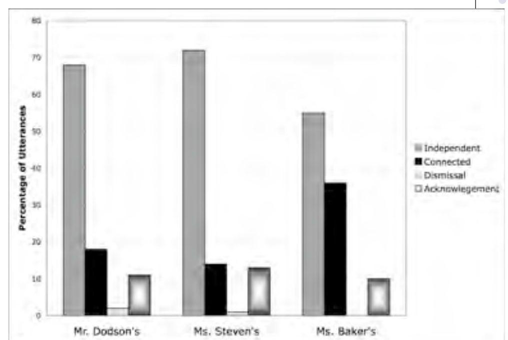
Discourse: Methods - Teachers' Questions

Code	Description
Open	A content question with many possible answers where the teacher is not looking for a specific response.
Closed	A content question with limited correct answer(s).
Rhetorical	A question for which an answer is not solicited identified by continuous talk by the teacher.
Managerial	A non-content question that is used to organize or manage the class.

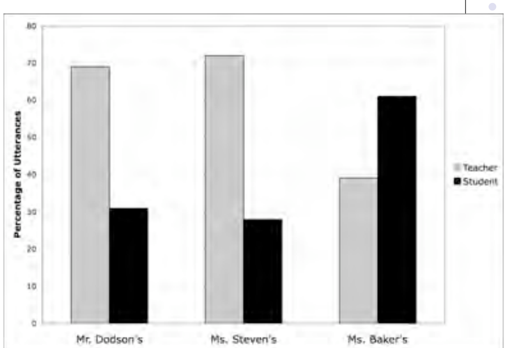
Results:
Argument Structure



Results:
Dialogic Interactions



Results:
Teacher-Student Discourse



Results:
Teacher-Student Discourse

	Mr. Dodson	Ms. Stevens	Ms. Baker
TS (1)	62	23	38
TSS (2)	4	1	14
TSSS (3)		2	3
TSSSS (4)		1	4
TSSSSS (5)			5
TSSSSSSS (7)			2
TSSSSSSSSSSS (11)			1

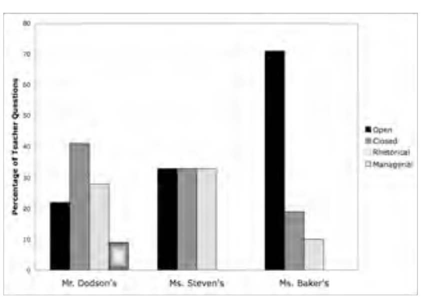
Results:
Ms. Baker

	Classroom Transcript	Structure	Dialogic	Question
Jamar:	Maybe the sun is too old.	*Reasoning*	*Connected*	
Ms. Baker:	Maybe the sun is too old?/You think that has to do with global climate change?	*Question* *Question*	*Connected* *Connected*	*Open* *Open*
Jamar:	It's like dying out.	*Reasoning*	*Independent*	
Ms. Baker:	But Sam is saying that in places it's actually not warm it's colder. Or in other in some places too warm in other places it's too cold.	*Evidence*	*Connected*	
Jamar:	It's colder cuz it's dying out.	*Reasoning*	*Connected*	
Maria:	It's probably, it's probably the way it's tilting.	*Reasoning*	*Connected*	
Alesha:	Yeah, that's why it's tilting like it's in different places.	*Reasoning*	*Connected*	
Maria:	Or maybe because it's more um environmentally friendly. That, like that part. Like they say that they get holes in the atmosphere/ so maybe where the holes are is above cities.	*Reasoning*	*Independent*	

Results:
Mr. Dodson

	Classroom Transcript	Structure	Dialogic	Question
Mr. Dodson:	What was the evidence that was presented in the video? / Let's. For ah Donna, / What was some of the evidence presented?	*Question* *Other* *Question*	*Dismissal* *Independent* *Independent*	*Rhetorical* *Closed*
Donna:	It had examples of areas that was	*Other*	*Independent*	
Mr. Dodson:	Sorry. Which, which video are you talking about?	*Question*	*Connected*	*Closed*
Donna:	The first video. / It had examples of areas that were like all ice. At one point, like um they were gone. The ice was gone. And then on, and then it showed the after picture and it was either all gone or all (inaudible).	*Other* *Evidence*	*Independent* *Independent*	
Mr. Dodson:	Right. / It was showing all these, uh, glaciers and, and uh, so ice melting. / They showed that in the first video. / Right? / They showed uh, uh, Kilimanjaro. / Marcus.	Other Evidence O/Question Evidence/O		*Rhetorical*
Marcus:	Yeah, uh, I found the first video like kind of hard to like understand.	Other	*Independent*	

Results:
Role of the Teacher



- Teacher connects to previous student comment
  - Mr. Dodson - 1, Ms. Steven's - 0, Ms. Baker - 5

Results:
Summary by Teacher

	Argument Structure	Dialogic Interactions	Role of Teacher
Mr. Dodson	Prevalent. Less focus on evidence and reasoning	Teacher directed. Few between student interactions	Predominately closed questions Rarely connects to other students
Ms. Stevens	Prevalent. Less focus on evidence and reasoning	Teacher directed. Few between student interactions	Equal distribution of open, closed and rhetorical questions. Never connects to other students
Ms. Baker	Prevalent. More focus on evidence and reasoning	Dialogic interactions between students more prevalent	Predominately open questions Connects to other students

Discourse: Conclusion

- Ms. Baker's use of *open questions* may have encouraged more student participation and reflective discourse.
- Ms. Baker's explicit *connections to previous students' contributions* may have encouraged students to consider multiple views.
- Developing a classroom culture of "reflective discourse" (Van Zee & Minstrell, 1997) may be essential for supporting scientific argumentation in k-12 classrooms.

Learning Progression

Level of Complexity	Framework Sequence
Simple	Variation #1 1. Claim 2. Evidence
	Variation #2 1. Claim 2. Evidence 3. Reasoning
	Variation #3 1. Claim 2. Evidence • Appropriate • Sufficient 3. Reasoning
	Variation #4 1. Claim 2. Evidence • Appropriate • Sufficient 3. Reasoning • Multiple components
Complex	Variation #5 1. Claim 2. Evidence • Appropriate • Sufficient 3. Reasoning • Multiple components 4. Rebuttal

Conclusions Across Studies

- Both curricular scaffolds and teacher instructional practices can support students' written arguments.
  - Different supports need to be synergistic
  - More effective when they provide both general and context specific support.
- Creating a classroom culture of reflective discourse through teacher moves may promote argumentation.
  - Teacher's use of open questions
  - Teacher modeling connections to previous students' ideas
- Different variations of the framework can be introduced to students over time as their abilities increase, which may support student learning of this complex practice.

More Information

- Kate's Contact information
  - kmcneill@bc.edu
- Powerpoint presentation
  - www.katherinelmcneill.com
    - Presentations --> Invited Presentations

- Thanks to Many
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    - Center for Curriculum Materials in Science (CCMS) (ESI-0227557)
    - Urban EcoLab (*ESI-0607010).*
    - Supporting Grade 5-8 Students in Writing Scientific Explanations project (DRL 0836099)

Hyperlinked Slides

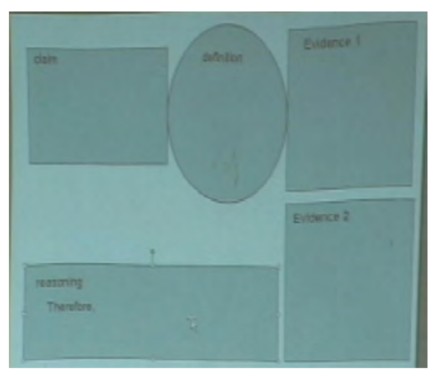
Alignment Between Curriculum and Teacher

Connect to Everyday Examples

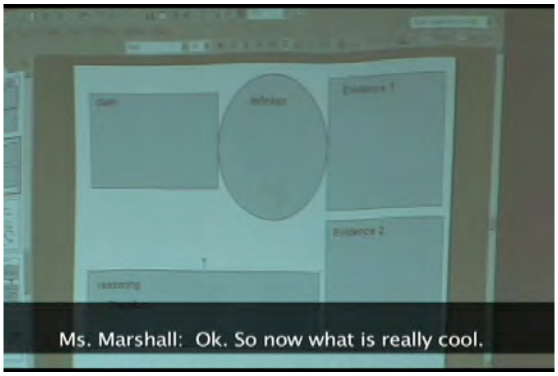
Alignment Between Curriculum and Teacher

Providing Students With Feedback

Modified Definition of Scientific Explanation



Modified Definition of Scientific Explanation



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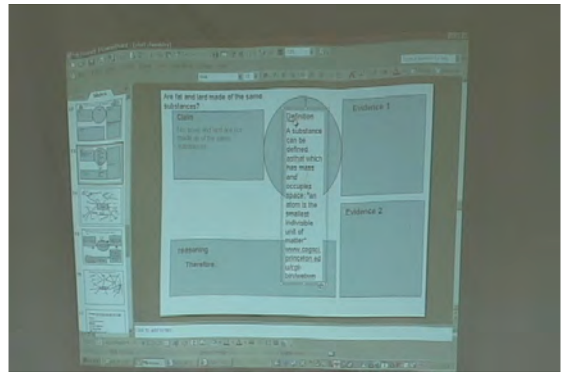
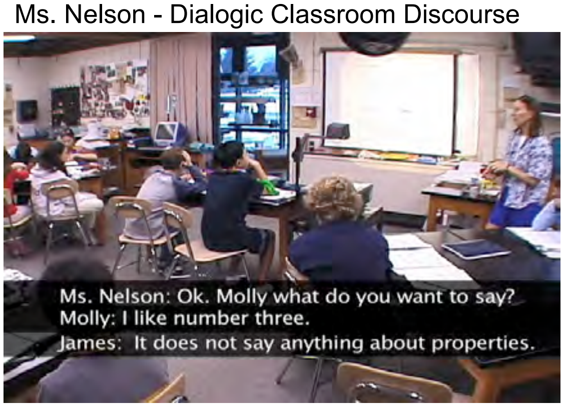


Ms. Nelson - Dialogic Classroom Discourse



Variation #1 (potential starting place)

- Claim
  - A statement that answers the question
- Evidence
  - scientific data that supports the claim

Variation #1 - Plant Example

The plant that received more light grew taller. (claim) The plant with 24 hours of light grew 20 cm. The plant with 12 hours of light only grew 8 cm. (evidence)

Variation #2 - Add Reasoning

- Claim
  - A statement that answers the question
- Evidence
  - scientific data that supports the claim
- Reasoning
  - a justification for why the evidence supports the claim using scientific principles

Variation #2 - Add Reasoning

The plant that received more light grew taller. (claim) The plant with 24 hours of light grew 20 cm. The plant with 12 hours of light only grew 8 cm (evidence) Plants require light to grow and develop. This is why the plant that received 24 hours of light grew taller. (reasoning)

Variation #3 - More Complex Evidence

- Claim
  - A statement that answers the question
- Evidence
  - scientific data that supports the claim
  - Data needs to be appropriate
  - Data needs to be sufficient
- Reasoning
  - a justification for why the evidence supports the claim using scientific principles

Variation #3 - More Complex Evidence

The plant that received more light grew more. (claim) On average for the six plants that received 24 hours of light, they grew 20 cm, had six yellow flowers, had fifteen leaves and they were all vibrant green. On average for the six plants that received 12 hours of light, they grew 8 cm, had two yellow flowers, and had four leaves. Also, two of the plants had zero flowers. These plants were still vibrant green, but they were smaller with fewer flowers and leaves. (evidence) Plants require light to grow and develop. This is why the plant that received 24 hours of light grew more (reasoning).

Variation #4 - More Complex Reasoning

- Claim
  - A statement that answers the question
- Evidence
  - scientific data that supports the claim
  - Data needs to be appropriate
  - Data needs to be sufficient
- Reasoning
  - a justification for why the evidence supports the claim using scientific principles
  - each piece of evidence may have a different justification for why it supports the claim

Variation #4 - More Complex Reasoning

Plants need water, carbon dioxide and light to grow. (claim) On average for the six plants that received constant light, carbon dioxide and water, they grew 20 cm, had six yellow flowers, had fifteen leaves and they were all vibrant green. On average for the six plants that received 12 hours of light, limited carbon dioxide and limited water, they grew 8 cm, had two yellow flowers, and had four leaves. Also, two of the plants had zero flowers. These plants were still vibrant green, but they were smaller with fewer flowers and leaves. (evidence) Photosynthesis is the process where green plants produce sugar from water, carbon dioxide and light energy. Producing sugar is essential for plant growth and development. That is why the plants that received a constant source of water, carbon dioxide and light grew the most. (reasoning)

Variation #5 - Add Rebuttal

- Claim
  - A statement that answers the question
- Evidence
  - scientific data that supports the claim
  - Data needs to be appropriate
  - Data needs to be sufficient
- Reasoning
  - a justification for why the evidence supports the claim using scientific principles
  - each piece of evidence may have a different justification for why it supports the claim
- Rebuttal
  - describes alternative explanations and provides counter evidence and reasoning for why the alternative is not appropriate.

Variation #5 - Add Rebuttal

Plants need water, carbon dioxide and light to grow. (claim) On average for the six plants that received constant light, carbon dioxide and water, they grew 20 cm, had six yellow flowers, had fifteen leaves and they were all vibrant green. On average for the six plants that received 12 hours of light, limited carbon dioxide and limited water, they grew 8 cm, had two yellow flowers, and had four leaves. Also, two of the plants had zero flowers. These plants were still vibrant green, but they were smaller with fewer flowers and leaves. (evidence) Photosynthesis is the process where green plants produce sugar from water, carbon dioxide and light energy. Producing sugar is essential for plant growth and development. That is why the plants that received a constant source of water, carbon dioxide and light grew the most. (reasoning) Our experimental design just limited the amount of air the plants received not specifically the amount of carbon dioxide. So you could argue that plants need water, air and light. But we know that the process of photosynthesis requires carbon dioxide and not another gas (like oxygen), which is why we concluded specifically that the carbon dioxide was required for growth. If we could limit just the carbon dioxide in our design, we would have better evidence for this claim (rebuttal).