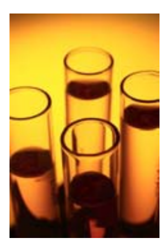
How do scientists explain their research? What can we learn from how science teachers teach science?

Colloquium on Research in Math & Science Education, UMass Lowell
Hannah Sevian
Associate Professor
Chemistry and Curriculum & Instruction
UMass Boston

We shall not cease from exploration
And the end of all our exploring
Will be to arrive where we started
And know the place for the first time.

– T. S. Eliot
(Little Gidding V from Four Quartets)

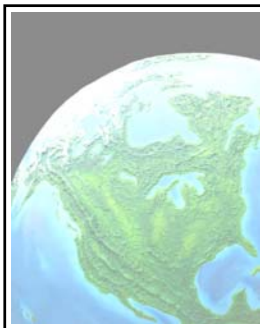


Presentation by a Science Graduate Student

This is a presentation to middle school students

- What is good about this presentation?
- What could be improved about this presentation?

<video>



The Problem

- How can you tell when a presentation of scientific research is good?
- How can you tell when it is poor?

The field of science education offers an answer to why some science research presentations are better than others.

Why is this important?

- Efforts by scientists to *communicate* the nature and results of scientific research are hindered by lack of training and emphasis on scientific communication to a general audience.
- Federal agencies have begun to place increased emphasis on scientists ensuring “broader impacts” of their research.
- A significant first step toward having broader impacts is understanding how to explain science effectively to a general audience.
- To learn about how scientists communicate science, we studied science graduate students in a GK12 program.

Explanations of Science

- Difficult to separate explanation of science from a deliberate attempt to teach
- Relevant research literature:
  1. Characterization of how science is explained by science teachers
  2. Types of knowledge that teachers possess

Types of Knowledge Teachers Possess

- Pedagogical knowledge
- Content knowledge
- Pedagogical content knowledge (PCK)

Research Questions

- ***How do science graduate students improve in their ability to explain their own research to a general audience of non-scientists?***

Research Questions

- ***How do science graduate students improve in their ability to explain their own research to a general audience of non-scientists?***
    1. Characterize explanations of research by scientists to an audience of non-scientists
    2. Compare fellows pre- and post- fellowship year
    3. Compare to control group of non-GK12 fellows

- ***What can we learn by comparing how scientists present science to how science teachers teach science?***

Characterizing how scientists explain research

Characterize explanations of research by scientists to an audience of non-scientists

Hypothesis

Literature reveals that there are unique components to teacher knowledge. We therefore hypothesize that:

1. There may be unique components to scientific explanations.
2. These components can be identified.
3. The quality of these components can be judged in the context of the entire explanation.

Development of a rubric to characterize scientific explanations

- We asked science graduate students *impromptu* to

  Explain your own research to an audience of non-scientists in 3 to 5 minutes

  and we videotaped and transcribed the presentations
- Four years of data - explanations prior to involvement in the GK12 program and after one year
- Thirty-two science graduate students representing diverse cultural backgrounds in various stages of M.S. and Ph.D. programs
- Videos and transcripts were coded and analyzed qualitatively

Analysis of the videos and transcripts

1. *Videos*: Are there discernable patterns in the ways in which graduate students explain their research?
   - Coded at first according to discrete activities in which science teachers engage when explaining science (Ogborn et al, 1996)
2. *Transcripts*: Closer analysis and coding allowed us to identify amount and accuracy of science contained in explanations and specific pedagogical skills.
   - Some graduate students integrated science content and pedagogy in superior ways
   - Reorganized rubric

How science is explained by science teachers

- **Cognitive operations that science teachers use when explaining science to students effectively can be characterized as a set of concrete practices (Ogborn et al, 1996)**
  - Create a need for an explanation by "transforming" what is familiar to students into something unfamiliar, often through the use of analogies and stories
  - Scaffold explanations so that they build on and connect to each other across various lessons
  - Rely on diagrams and gestures to aid in explanation
  - Develop explanations of scientific phenomena as stories with protagonists (independent variables), context, causes & effects (action), climax, and moral (which is the model)

The Rubric

The rubric runs parallel to what we know about effective science teaching – that it requires three kinds of knowledge

1. Science content knowledge
2. Pedagogical knowledge
3. Integration of content and pedagogy in the service of a clear explanation

The Rubric: 1. Science content knowledge

Factual knowledge and processes and how well that knowledge is understood in broader contexts. Assesses accuracy and depth, including how well the scientist portrays the overall organization of knowledge.

- Factual knowledge
- Evidence of organization of knowledge by the guiding principles of the discipline
- Ability to transfer knowledge to broader contexts

The Rubric: 2. Pedagogical knowledge

The knowledge and skill involved in explaining major concepts involved in the scientist's research. Assesses methods scientists employ to communicate their knowledge orally to an audience, with written media to support in real-time.

- Structure and balance of presentation
- Response to the audience
- Choice of language
- Technical skill of presentation and use of media

The Rubric: 3. Integration of content and pedagogy

Assesses the ability to integrate content and pedagogy in the service of a clear, coherent, and engaging explanation of scientific research.

- Development of appropriate mental images to support explanation
- Tactical use of media
- Scaffolded explanation

Presentation by a Science Graduate Student

Use rubric excerpt to evaluate the quality of the presentation

- Video
- Transcript

<video>

Findings from using the rubric

1. Effective explanation of science is developed in layers
   - When an explainer is strong in only one type of knowledge (content or pedagogy), there is a clear transition in the person's explanation
2. Only when both pedagogy and content are strong is a scientific explanation effective
   - Science explanations in this category exhibit development of powerful mental images, tactical use of media to support explanation, and scaffolded development of concepts
3. Presentation skills add an extra layer that can cause a good presentation (transcript) to fail (video) and a poor presentation (transcript) to appear to succeed (video)
4. Gestures sometimes reveal deep content understanding that the explainer is unable to articulate verbally

Characteristics of four types of explanations in science

	Weak content knowledge (of own research)	**Strong content knowledge (of own research)**
Weak pedagogical knowledge	• Unclear from start to finish.	• Engaging introduction that relates to audience but is unrelated to research, or big picture about research that is not relevant to audience. • Clear transition to more complex scientific explanation inappropriate for audience.
Strong pedagogical knowledge	• Strong introduction that establishes structure, and is engaging, clear, and relates the research to the audience. • Clear transition to explaining own science, unable to explain clearly.	• Clear logical structure, story maintained throughout explanation. • Explanation scaffolded throughout. • No transition.

Findings in the context of science education

Effective teachers display three kinds of knowledge (Shulman, 1987)
- Pedagogical knowledge
- Content knowledge
- Pedagogical content knowledge (PCK)
  - Knowledge about how to teach a specific subject matter for improved understanding and learning

- PCK as a construct has "fuzzy boundaries" (e.g., Gess-Newsome, 1999)
- How does/can PCK develop? (van Driel et al, 1998; Loughran et al, 2003)
  - Through experience of teaching coupled with strong subject matter knowledge
  - Form of knowledge that can be developed alongside pedagogical knowledge and content knowledge

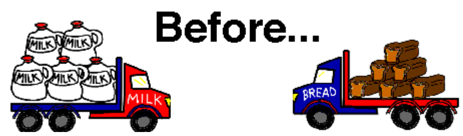
Applying science education to scientists

How do science teachers and scientists make use of the three kinds of knowledge when preparing and presenting explanations of science?

- Content knowledge
- Pedagogical knowledge
- Pedagogical content knowledge

What parallels exist between how science teachers use these kinds of knowledge and how scientists used these kinds of knowledge?

Pedagogical content knowledge in scientific research presentations



THE STORY

On an otherwise uneventful Monday morning, Bill the Baker and Moe the Milkman set about making their usual delivery rounds. Little do they know of the terrible misfortune in store for them both. As Moe cautiously approaches the corner of Broadway and 113th St., he is shocked to see Bill's Bread Truck suddenly burst into flames. Moe, realizing that the only way to save his pal Bill is to steer his liquid cargo directly into the ensuing flames, hesitantly but courageously does so. Luckily both men escape with minor injuries, but their precious cargos have been mixed up. Less than a second later, a wild horde of ambulance chasers arrive and begin photographing the accident scene with their new ultra-high resolution cameras. After consulting with his lawyer, Bill decides to sue Moe for damages, claiming that his truck was never on fire. Good thing they took those photos! The cameras are so powerful that from the photos investigators can not only count how many bread loaves and milk bottles are on each truck, but they can even distinguish loaves of pumpernickel from loaves of rye and bottles of skim milk from bottles of whole milk. Moe's lawyers make use of the amazingly accurate evidence to reconstruct the conditions of the crash, including the speeds and trajectories of the two vehicles, and thereby prove Moe's innocence.

from http://www.columbia.edu/cu/chemistry/groups/flynn/bm.html

Pedagogical content knowledge in scientific research presentations

THE EXPLANATION

- In our research, the trucks we collide are vibrationally excited molecules (typically large aromatic hydrocarbons like pyrasine, methyl pyrasine, pyradine, pyrimadine, & C_6F_6) with room temperature bath molecules (typically CO_2 & CO). Our cameras are high-resolution infrared diode lasers and the bread loaves and milk bottles we observe are the post-collision vibrational, rotational and translational degrees of freedom of the bath molecules on a single-collision time scale. From these snapshots, we gain information about the the collision itself.
- For example, we can determine the average energy transfer/collision and the probability of this transfer and then construct a probability distribution, P(E, E'), for the energy transfer. This in turn allows us to calculate the unimolecular decomposition rate constant, which describes how long it would take for the vibrationally molecules to decompose had the bath molecules not "extinguished" the excited state. Sort of like the police using the crash photos to determine how long Bill had to live before his truck would explode had it not been for Moe's quick thinking.

from http://www.columbia.edu/cu/chemistry/groups/flynn/bm.html

Further Study

1. Apply rubric to large numbers of science graduate students to learn more about science explanation skills and strategies that scientists need most assistance in developing
2. Independently test for content knowledge, pedagogical knowledge, and pedagogical content knowledge to determine whether there is a correlation between performance in these and evaluation of science explanations using our rubric
3. Study more data over time to further understand nature of the progression of GK12 fellows toward effectiveness in explaining science
4. Compare GK12 fellows with a control group of graduate students not in the GK12 program to assess impacts of GK12 program on improving scientists' ability to explain science to a general audience

Acknowledgments

"Analysing how scientists explain their research." Co-authored with Lisa Gonsalves. Accepted to *International Journal of Science Education* (2007).

Manuscript in preparation, with Lisa Gonsalves and Robert Chen, on trajectories toward greater effectiveness in scientific explanations by science graduate students.

Dedham Middle School Milton Public Schools FOCUS On Children Boston Public Schools

We thank the GK12 fellows who participated in this research. We thank Prof. Robert Chen for meaningful contributions to the research.

UMASS BOSTON

This work is supported by NSF awards DGE-0231638 and DGE-0538445.

NSF