The role of experimental and historical sciences in classroom inquiry

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Science studies in science education

• Expanding beyond philosophy and history of science

• Importance of a mediator

• Context

• Micro vs. macro
What have we learned from...

Nature of science
- NGSS
- Scientific practices
- Controversial topics

Scientists
- History of science
- Sociology of science

Philosophy of science

...to inform our work in the K-12 context?
The Problem

• The development of classroom inquiry experiences requires an understanding of how scientists actually do their research.

• As these experiences can only be approximations of scientific practice, decisions about the images of science we provide to students must be made.

• These decisions impact the way in which students view science as a whole and the relationship of fields of science.

• Science educators have primarily provided an image of science taken from physics (experimentation, replication, etc.)

• Left out are the fields of science that do not entirely rely on experimentation (geology, evolutionary biology, cosmology). This implies these are less legitimate.
Impacts

This lack of focus on non-experimental sciences has impacts:

• Access to geology in K-12 curriculum (Dodick & Orion, 2003)
  – Historically thought of as a derivative of physics and neglected in school curricula.
  – Led to limited engagement in geology for students.
  – Affects student understandings of other subjects

• Acceptance of evolution (Rudolph & Stewart, 1998)
  – Evolution has been singled out as being “unscientific” because it cannot be justified experimentally.
Impacts

**DEFINE TERMS CORRECTLY:**

“Is creation a viable model of origins [CREATION/EVOLUTION] in today’s modern scientific [SCIENCE] era?”
Purpose

• To use the construct of experimental and historical sciences to provide teachers and students a richer image of ‘authentic’ scientific practice

• To examine the scientific practices described in the *Framework for K-12 Science Education* from the perspective of the historical sciences

• To provide an expanded language of science inquiry for use in the classroom
• Providing a reasonably authentic context for science learning requires a greater understanding of the actual methods of inquiry as practiced in diverse disciplines.

• Ethnographic studies (e.g., Latour & Woolgar, 1979; Traweek, 1992) and those from cognitive scientists (Dunbar, 1995; Giere, 1988; Nersessian, 2009) have studied activities in a variety of sciences.

• With few exceptions (e.g., Latour, 1999) the vast majority of these studies have addressed experimental sciences such as physics and chemistry while leaving out historical sciences that utilize observational data as a primary source of evidence.
Background

• A concentration on experimental sciences leads to a mistaken impression that science disciplines in general operate in a similar way in terms of their methodologies and types of reasoning employed.

• Lack of focus on historical sciences (e.g., paleontology, cosmology, evolutionary biology) in studies of science-in-action. What do we draw from?

• Domain of philosophers of science (e.g., Brown, 2011; Cleland, 2002; Jeffares, 2009) and scientists themselves (e.g., Diamond, 1997; Gould, 1986, Mayr, 1985).

• Distinction between experimental and historical sciences largely based on epistemological differences from which methodological differences have arisen.
Not all scientists agree

- **Ernest Rutherford**: “science is either physics or stamp collecting” (as cited in Dott, 1998).

- **Lord Kelvin**: “nothing is science if it cannot be quantified” (as cited in Dott, 1998).

- Even physicist **Luis Alvarez** disparaged fields like paleontology for not doing “real science” (as cited in Gould, 1989).

- **Henry Gee**: historical sciences are “subjective… as they can never be tested by experiment, and so they are unscientific. They rely for their currency not on scientific test, but on assertion and the authority of their presentation” (1999, p. 5).
Philosophy of Science

- Philosophers of science have taken on these critiques:

  - Cleland (2001; 2002; 2011; 2013):
    - Historical sciences have evolved methodologies to cope with the overdetermination of past events whereas experimental sciences have similarly evolved other methodologies to cope with the underdetermination of future events.

Two types of science

• **Experimental sciences** – ask questions in which direct experimentation is possible. Therefore knowledge is constructed through controlled experiments in which natural phenomena are manipulated, often in order to test a single hypothesis. *(e.g., chemistry, physics, molecular biology)*

• **Historical sciences** – gather evidence by observation because direct experimentation is usually impossible. These sciences often utilize observational evidence in order to investigate ultimate causes from the past whose effects must be interpreted from complex causal chains of events. *(e.g., paleontology, cosmology, evolutionary biology)*
Two types of science

Four distinctions between the two:

- Epistemic goal
- Nature of objects under study
- Method of evidence construction
- Quality standards

(adapted from Diamond, 1997; Dodick, Argamon, & Chase, 2009)
Two types of science

<table>
<thead>
<tr>
<th></th>
<th>Experimental Sciences</th>
<th>Historical Sciences</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Epistemic goal</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The nature of phenomena under study</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Method of evidence construction</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Quality standards</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Examples</strong></td>
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<td></td>
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A note on experiments

• It is important to note that, while the historical sciences are not justified experimentally, historical scientists do conduct experiments and utilize laboratory methods.
  – Experiments conducted in genetics and biochemistry have been instrumental in the development of evolutionary biology.
  – Radiometric dating methods, grounded in statistical laws of quantum mechanics, are essential to multiple historical sciences.

• In historical sciences, experiments are a means to an end as opposed to an end in itself. (Jeffares, 2008)
A note on dichotomies

Cleland (2002)
A note on dichotomies

A note on dichotomies

The distinction between historical and [experimental] sciences runs through rather than between academic disciplines. (Tucker, 2014, p. 347)
Historical sciences in science education


- Evolutionary Biology - Passmore & Stewart (2002); Rudolph & Stewart (1998)

- Dodick, Argamon & Chase (2009)

- Gray & Kang (2013)

- Curriculum – e.g., *Adventures in Paleontology* (NSTA Press)
An Expanded Language of Inquiry

“Language is a system of resources for making meaning.” (Lemke, 1990, p. ix)

• The language of classroom science inquiry:
  – Experiment, control, variable, prediction, hypothesis, etc.

• To this we should add:
  – Retrodiction
  – Abduction
  – Reasoning from analogy
  – Multiple working hypotheses
An Expanded Language of Inquiry

“Language is a system of resources for making meaning.” (Lemke, 1990, p. ix)

• The language of classroom science inquiry:
  – Experiment, control, variable, prediction, hypothesis, etc.

• To this we should add:
  – **Retrodiction**
    • Definition: An inference about past events.
    • Example: Scientists tested the asteroid hypothesis by searching for impact debris, glass, shockwaves, tsunami debris, and an impact crater.
  – Abduction
  – Reasoning from analogy
  – Multiple working hypotheses
An Expanded Language of Inquiry

“Language is a system of resources for making meaning.” (Lemke, 1990, p. ix)

• The language of classroom science inquiry:
  – Experiment, control, variable, prediction, hypothesis, etc.

• To this we should add:
  – Retrodiction
  – Abduction
    • Definition: A type of inference in which an explanatory hypothesis is generated.
    • Example: Darwin presented an extended argument for natural selection as the best hypothesis for explaining the available evidence.
  – Reasoning from analogy
  – Multiple working hypotheses
An Expanded Language of Inquiry

“Language is a system of resources for making meaning.” (Lemke, 1990, p. ix)

• The language of classroom science inquiry:
  – Experiment, control, variable, prediction, hypothesis, etc.

• To this we should add:
  – Retrodiction
  – Abduction
  – Reasoning from analogy
    • Definition: Utilizing present causes to explain similar events in the past.
    • Example: The reconstruction of the locomotion and behavior of extinct animals based on similarities with extant animals.

  – Multiple working hypotheses
An Expanded Language of Inquiry

• “Language is a system of resources for making meaning.” (Lemke, 1990, p. ix)

• The language of classroom science inquiry:
  – Experiment, control, variable, prediction, hypothesis, etc.

• To this we should add:
  – Retrodiction
  – Abduction
  – Reasoning from analogy
  – Multiple working hypotheses
    • Definition: The process by which multiple possible hypotheses are generated and systemically compared against the evidence.
    • Example: Hypotheses to explain the extinction of the dinosaurs included random chance, a magnetic reversal, a nearby supernovae, and volcanic activity.
A Shift Toward Practices

1. Asking questions
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
7. Engaging in arguments from evidence
8. Obtaining, evaluating, and communicating information
Examining the *Framework*

- General enough to encompass inquiry across the continuum of experimental and historical sciences.

- The authors of the *Framework* state that they are written in a way as to not “overemphasize experimental investigation at the expense of other practices” (p. 3-2).

- However, in the descriptions of each of the practices the authors prioritize experimental over historical sciences.
Representing the practices in the framework

1. Asking questions
2. Developing and using models
3. Planning and carrying out investigations
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6. Constructing explanations
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- Examples (particle theory of matter, ideal gas law, atomic theory, gravitational forces, electromagnetic waves)

- Examples (big bang, Darwin’s theory of evolution)
Examining the *Framework*

- The epistemological and methodological differences reveal small but significant differences in the way the practices may be enacted across the disciplines.
Scientific practices

- Asking questions
- Developing and using models
- Planning and carrying out investigations
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- Obtaining, evaluating, and communicating information
**Scientific practices**

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- Developing and using models
- Planning and carrying out investigations
- Analyzing and interpreting data
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**Historical** - ask questions about unique entities that cannot be manipulated experimentally (e.g., what caused the Permian extinction?)

**Experimental** - ask questions about uniform entities for which experimentation is possible (e.g., what is the structure of DNA?).
Scientific practices

**Historical** – Largely observational methods utilizing retrodictions, abductive reasoning, etc.

**Experimental** – Largely experimental (manipulation of natural phenomenon).
Scientific practices

- Asking questions
- Developing and using models
- Planning and carrying out investigations
- Analyzing and interpreting data
- Using mathematics and computational thinking
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**Historical** – Evidence it utilized to evaluate multiple possible hypotheses in order to narrow down to the most likely explanation.

**Experimental** – Evidence compared to prediction.
Scientific practices

- Asking questions
- Developing and using models
- Planning and carrying out investigations
- Analyzing and interpreting data
- Using mathematics and computational thinking
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- Engaging in arguments from evidence
- Obtaining, evaluating, and communicating information

**Historical** – Most often in narrative form and only relevant for the unique phenomenon under study. Not used to generate further predictions.

**Experimental** – Often generalizable to similar phenomena and can be used to generate further predictions.
Scientific practices

- Asking questions
- Developing and using models
- Planning and carrying out investigations
- Analyzing and interpreting data
- Using mathematics and computational thinking
- Constructing explanations
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- Obtaining, evaluating, and communicating information

Historical – Larger amount of evidence needed. Increased qualifiers, rebuttals.

Experimental – Smaller amount of evidence needed.
Implications

• **Activities and curricula:**
  – E.g., Diamond & Zimmers, 2006; Dempsey, Bodzin, & Cirucci, 2012; Hansen & Slesnick, 2006; Kastens & Turrin, 2010; McGarry, Straffon, & Patterson 2012

• **Science teachers:**
  – Familiarize themselves with unique methodologies, concepts, terminology

• **Science teacher educators:**
  – Provide authentic images and examples of historical sciences

• **Curriculum developers:**
  – Focus on not only the end results, but the practices of historical sciences
Conclusion

• Inquiry and the National Science Education Standards (2000)

• Describe scientific inquiry as “the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work” (p. 1), a definition inclusive of the historical sciences.

• Learning from the history of INSES
Conclusion

• The distinction between experimental and historical sciences provides a framework from which to more fully integrate the ways in which researchers in the historical sciences construct new knowledge.

• It is not enough to focus on the end products of science. The ways in which the community of scientists made those discoveries are vital as well.

• The distinct methodologies and patterns of reasoning and arguing employed in the historical sciences needs to be included in our classroom inquiry experiences to give students a richer and more complete image of science.
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