Using Historical Narratives to Guide Science Experiments

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ABSTRACT: Hands-on experimentation in science education is often considered to have an obvious value. This paper traces the history of experimentation in science education with the intention of illustrating the roots of the strict empirical design that results in a "laboratory-inquiry" style of instruction. In this style, a lecture introduces the terms, characteristics and behaviour of phenomena, and the derivation of equations needed to solve for some unknown quantity. In the laboratory, procedures are written in worksheets that detail each step to guarantee the experiment will work and reveal the "correct" result. Even though the student knows the outcome before they do the experiment, the experiment claims to "prove" that the laws are correct.

An alternate view of experimentation will be presented that is informed by Gerald Rutherford's (1964) view of inquiry and guided by Mathews (1994) critique "that messing about with real objects" cannot reveal the structure of the scientific theories that apply to those objects. Rutherford, one of the original authors of the Harvard Project Physics course which emphasized the history of science, differentiated between inquiry as technique and inquiry as content. He suggests that for inquiry as content the concepts of science are understood only in the context of how they were arrived at, and of what further inquiry they initiate. Rutherford maintained that "To separate scientific content from scientific inquiry is to make it highly probable that the student will properly understand neither". Rutherford also cautions us that the progress toward teaching science as inquiry will remain unsuccessful if teachers do not cultivate an understanding in the history and philosophy of science.

I will illustrate how a historical narrative can be used to achieve Rutherford's model of inquiry as a means to help students deal with, not only the manipulation of objects, but also ideas. Further, I will argue that this type of approach will better address the problems of teaching and understanding the nature of science that have plagued us for years.

Introduction

Curriculum reforms in science education are being declared "shipshape" worldwide as science educators and their administrators struggle tenaciously to implement the kind of changes advocated in various curriculum documents. While some of the reforms serve to merely re-arrange the chairs on the deck of the Titanic, other aspects of these curriculum initiatives focus on new interests. Of particular interest is the attention given to the history and nature of science as a fundamental principle of scientific literacy. The influential Science for All Americans (AAAS, 1989) assigns the most prominent position in the document - chapter 1 - to the Nature of Science and includes a complete chapter on historical perspectives recognizing that "episodes in the history of the scientific endeavour are of surpassing significance to our cultural heritage". Several other countries have also aligned with this view (McComas & Olson, 1999) profiling science more as a humanistic activity in contrast to a compilation of unrelated scientific facts and concepts.

Given our record of teaching and learning the history and nature of science, these reforms are clearly due. For many years, research in the nature of science has illustrated that students generally hold a naive view of the nature of science, their teachers don't seem to be much better, and even when they do hold adequate views of the nature of science they don't act on them (Brickhouse, 1990, Lederman,1992, Lederman,1995, Abd-El-Khalick & Lederman, 2000). However, as teachers begin addressing these reforms it is becoming all too apparent that we lack a tradition of teaching the history and nature of science. Although the history and philosophy of science (HPS) has been advocated by many historians, philosophers, and educators for many years (Winchester, 1989, Mathews, 1994, Lederman, 1998), we have only lately started to detail more clearly some potential implementation strategies in the classroom (Allchin, 1999, Monk & Osborne, 1997, Stinner, MacMillan, Metz, Klassen & Jilek, 2003, Metz & Stinner, 2004).

Historical Views on Practical Work in Science Education

Some educators have described the importance of the hands-on activities in science instruction as "*too obvious to argue*." Many science classes meet every day in a laboratory and professional organizations, such as the National Science Teacher's Association, promote hands-on activities as an integral component of science teaching. Although laboratory activities have become widely recognized as essential in science education, we continue to clearly explicate the relationship between the laboratory experience and instruction.

Typically, a lab experience is considered to involve students' interactions with physical objects in a natural setting in order to observe and quantify scientific phenomena. These experiences may include design and planning, measurement and data collection, construction and assembly of apparatus, analysis, interpretation, synthesis and application of results. Any reference to a laboratory experience implies that the student is directly involved with the activity. Laboratory activities may be exploratory in nature or they may be more formal situations that include a rigorous analysis of data.

The success of the laboratory in the development of scientific theories has been a hallmark in modern science since Galileo rolled a ball down an inclined plane. It was inevitable that the laboratory experience would inspire instructional strategies as university preparatory schools (prep schools) began to emerge in North America at the beginning of the 19th century. Although instruction primarily centred on the textbook, some innovative professors were beginning to purchase scientific apparatus to perform demonstrations to improve their instruction. By the turn of the century, most high school textbooks and laboratory manuals included quantitative measurement as a major part of their work (Kapuscinski,1981).

Riding the wave of economic and population expansion, new universities began to emerge throughout North America fostered by the 1862 U.S. federal government land grants. Curriculum reform witnessed old subjects like Latin and Greek dropped in favour of the sciences and the practical arts. Universities helped to motivate prep schools toward the value of laboratory instruction by changing their entrance requirements. The requirements at Harvard University now included "a course of experiments in the subjects of mechanics, sound, light, heat, and electricity, not less than forty in number, actually performed by the pupil" (Admission to Harvard College in 1887, in Rosen, p. 200). The Harvard list advocated 50% instruction in laboratory experiments, and 50% instruction from the textbook. E.H. Hall (1913), a noted Harvard physicist, designed a "College Laboratory Manual for Physics" for the Harvard list that became the trademark text for laboratory science.

At this time, the laboratory experience had consolidated around the Harvard list and it was natural for philosophers to begin to question these new methods. An ardent commentary soon emerged in the writings of John Dewey (1910). Dewey was an educational philosopher with some exposure to the natural sciences in his undergraduate studies. He also had high school teaching experience and a keen interest in education. Dewey reasoned that the psychological processes of learning should guide our instruction. He espoused the benefits of individual experiences through the active engagement of the learner with their environment. Additionally, he advocated the importance of scientific method (defined broadly), that is, the processes through which we acquire scientific knowledge and not the content. For Dewey, it was not enough to fill students through "information hoppers" with an abundance of scientific facts. An individual's experiences supplied the framework the learner needed to formulate meanings. Dewey criticized current education practices that treated science as subject matter, which were "breaking down because of its sheer mass."

The early supporters of laboratory instruction often acknowledged the technical aspects of practical work as the major benefit of the laboratory experience. However, Dewey recognized that the laboratory experience should be much more than manipulating physical objects.

> Many a student has acquired dexterity and skill in laboratory methods without it every occurring to him that they have anything to do with constructing beliefs that are alone worthy of the title of knowledge. (p. 124)

Even though Dewey highlighted that practical experiences should embrace ideas and critical thinking, the more traditional approach to practical experiences which emphasized data collection and verification of known laws, such as found in the Harvard list, continued to prevail.

The curricular reforms of the 1960's were heralded as a significant break from the past. Shymanksy et al.(1983) marked a clear delineation between "traditional" curriculum and the new "inquiry-based" paradigms of instruction. The "new" curriculum (post 1955) emphasized the nature, structure, and processes of science, higher cognitive skills and integrated laboratory activities into the core of the instruction. Such inquiry-based learning focussed on science process skills that promoted observation, classifying, measurement, and controlled experimentation using independent and dependent variables. Educators often called the inquiry style of teaching "guided discovery" where the teacher's role was to facilitate their students' actions as they performed the same tasks of discovery as real scientists.

The ideals of a meaningful approach to inquiry soon gave way to an implementation of inquiry that was quite different. Harris and Taylor (1983) summarized the philosophical problems associated with inquiry-based instruction. They claimed that inquiry, or "discovery" learning, favoured abstraction and the confirmation of theories. Abstraction implied a view that meaning was embedded in, and could be drawn out of objects, while the verification of existing theories left no room for alternative explanations. In this view, the job of the scientist was to uncover nature's laws. Subsequently, this account of science inevitably leads to a set of illusions about the scientific enterprise, including the naive portrayal of experimentation as a definable method preceding directly from observation to theory.

In practice, inquiry methods seem to reflect this criticism. Schwartz, Lederman, and Thompson (2001) followed one teacher's experience with teaching science as inquiry (SI) in terms of developing the students' understanding of the nature of science (NOS). After instruction by inquiry, students generally maintained their naive views with respect to the nature of science and the researchers concluded that the state of science education and science education reform is the same today as it was 100 years ago. They contend that we continue to achieve the "holy grail of in-depth understanding of scientific concepts" while failing to provide students with the critical organizing themes of NOS and scientific inquiry. We still expect that students and their teachers will come to know and understand NOS by simply doing science even though doing science through inquiry presents and promotes a rather naive view of science. The researchers strongly called for a more explicit form of NOS instruction that emphasizes that science is done by humans. They conclude that "without explicit attention afforded to relevant aspects of NOS and SI, even within the context of inquiry-based experiences, learners' views of NOS and SI will likely remain unchanged.

Importantly for this paper, Mathews (1994) has argued convincingly that teachers' unfamiliarity with the history and philosophy of science prevents teachers from avoiding the naive claims of inquiry and discovery learning. Mathews echoes Dewey's earlier critique

> that scientific method is inductive, that observation does not depend upon conceptual understanding, and that messing about with real objects can reveal the structure of the scientific theories that apply to those objects. (p. 28)

Yet today, the dominant mode of instruction remains this strict empirical design, partially integrated into a lecture-laboratory style of instruction. Yager (1992) reported that

> For most students science becomes what is printed in textbooks and what is included on associated worksheets and in verification-type laboratories. (p. 906)

In the lecture-laboratory style of instruction the laboratory activity illustrates the information outlined in the classroom lecture. The lecture includes the definition of terms, characteristics and behaviour of phenomena, and derivation of equations needed to solve for some unknown quantity. In the laboratory, procedures are written in worksheets that detail each step to guarantee the experiment will work and reveal the "correct" result. All students do the same exercise, on the same apparatus, in the prescribed manner, to arrive at the same conclusion. This teaching style emphasizes the verification of scientific laws. Even though the student is given the relevant formula before they do the experiment, the experiment "proves" that the laws are correct. While the emphasis was purportedly on process, students simply followed "recipes" from manuals and memorized facts and laws. As a result, inquiry methods as practised in the classroom resembled traditional laboratory methods.

The fact that inquiry as practised in science classrooms is no different than a traditional approach is clearly illustrated by a comparison between Hall's (1913) techniques and those found in modern laboratory manuals. For example, in an exercise called "Pendulums", Hall uses a simple pendulum to find the value of the gravitational constant *g*. In his opening paragraph, Hall defines vocabulary, gives instructions on how to measure the length of the pendulum, and cautions the student to use a small swing of the pendulum. His opening remark is

> The "simple pendulum" as here used is a sphere of lead, about 1 cm. in diameter, suspended by a fine silk thread from the beveled edge of a wooden shelf, S, Fig. 6. (Hall, p. 11)

Fast forward to today's laboratory manual. In an activity called "The Pendulum", we find the opening sentence reads,

> A simple pendulum consists of a small, dense mass (called a bob) suspended by a nearly weightless cord from a point about which it can swing freely. Such a pendulum is shown in Figure 10-1. (Trinklein, 1990)

In his second paragraph, Hall instructs the student to measure the time for 100 swings, calculate the time for one swing, and using the given formula, find the value of *g* (and he adds that the width of the pendulum should be small). In today's version of the activity, the student is instructed to measure the mass, length, and time required for 20 swings (again the student is instructed to keep the amplitude small). Subsequently, data for several trials is entered in a table and students are directed to use the equation from the textbook to calculate *g*. In almost 100 years of practice this lecture laboratory style designed by Hall maintains an inertia that is almost impossible to change! One might invoke a "if it ain't broke, don't fix it" defence, but in the face of recent curriculum reforms and a broader call for scientific literacy, including an understanding of historical and cultural significance of science, our goals clearly do not match our methodology.

Matthews (1998) illustrates the opportunities lost to achieve these wider aims of scientific literacy. In a model lesson on the pendulum found in the Standards document (NRC, 1996) there is no mention of timekeeping, the pendulum clock, the longitude problem, European expansionism, nor any mention of historical figures who contributed significantly to scientific, historical, and cultural impact of the pendulum. Matthews concludes that

> There is not much point in hand-waving about liberal, or more expansive goals, for science education if nothing is done to assist teachers, or curriculum authorities, in realising them. (Matthews, p 204)

What then can we do for teachers? One possible solution may be to re-consider inquiry in light of its original intentions. McMillan (2001) reminds us that Schwab (1962) wanted teams of students to encounter phenomena, discuss possibilities, debate the feasibility and validity of different problems, consider methodologies, apportion responsibility, write reports, account for and resolve discrepancies, and then arrive at a consensus. Gerald Rutherford (1964), one of the original authors of the Harvard Project Physics course which emphasized the history of science, asserts that although we are opposed to the rote memorization of facts in science that there remains a significant difference between our practices and our convictions. Rutherford, like Matthews, attributes this difference to "a failure of those who call for change and innovation to provide teachers with effective models and materials". He also suggested that to be an effective teacher of science as inquiry we must understand that the conclusions of science are intimately connected with the inquiry that produced them. Rutherford inspires us to identify the close link between process and content by differentiating between two forms of inquiry. First, he described a commonplace form of inquiry found in school science, as technique, "using the method of scientific inquiry to learn some science". Then, Rutherford outlined inquiry as content, "operating on the premise that the concepts of science are properly understood only in the context of how they were arrived at and of what further inquiry they initiated". He held that "To separate scientific content from scientific inquiry is to make it highly probable that the student will properly understand neither. Rutherford further cautioned that the progress toward teaching science as inquiry will remain unsuccessful if teachers do not cultivate an understanding in the history and philosophy of science.

In an effort to make some progress toward a more authentic approach to inquiry, and to address the wider goals of scientific literacy through a historical perspective, I am suggesting that the time has arrived for us to consider the nature of hands-on activities and the organization of our laboratory manuals. The typical laboratory guide describes activities whereby students follow prescriptive and detailed instructions to gather and record data (Lunetta & Tamir, 1979; Fisher et al., 1999). Such a "cookbook" approach (Roth, 1994) rarely provides for Rutherford's version of inquiry as content where that the concepts of science are understood in the historical context of inquiry. I am proposing an alternative approach to laboratory investigations which incorporates a historical narrative which permits students to move between ideas and investigations. The intent, aimed at the criticism of Dewey and Mathews, is to direct students to manipulate ideas in addition to objects.

Recently Norris et al. (2005) have detailed the use of narrative as explanation. The author's outline several forms of narrative elements, such as narrative appetite, structure, agency, and purpose, which are considered to be essential components for advancing to narrative beyond a simple expository text. Additionally, Norris et al. advance a theory for "narrative as explanation" intended to make science more understandable through "expanding meaning; offering a justification; providing a description; or giving a casual account". This paper advances a form of narrative which is used as an explanatory device in collaboration with practical work based on historical experiments. In this way laboratory experiences include the manipulation of ideas through various interactions that involve the reader in an ongoing dialogue with the narrative.

The development of such a historical representation begins with an interesting narrative. Importantly, the narrative should include original works, modified if necessary for student consumption, and it is unveiled to students throughout the investigation. As it relates to the investigation, the narrative contains four parts:

1. Context
2. Experimental design.
3. Analysis and interpretation of results.
4. Explanation.

The introductory part of the narrative establishes a context with the inclusion of biographical information while raising a problem and/or confrontation. Research indicates that stories about scientists' personal lives can improve students' interest image of science and scientists (Seker, 2003) and that students reflect positively on early ideas of scientists (Metz, 2002). Students can research this introduction themselves, or it can written and presented directly by the teacher. The narrative is initially used to activate students' prior knowledge. Throughout the narrative students perform activities alternating between their ideas and the historical context. Differentiated instructional techniques, such as journal writing, field notes and sketches, and concept maps, are used to encourage student involvement through their written work and argumentation. In the next phase, groups of students collaboratively react to the problem or confrontation introduced by the narrative by proposing an experimental question and designing a solution to the problem. Students continually compare and contrast their ideas to the original work. After some reflection and revision, the teacher facilitates an experiment which closely parallels the historical experiment. At this time, students may also simultaneously perform independent investigations arising from their own proposals. Following the collection of data, the third part of the narrative is revealed and students once again compare and contrast their data and ideas with the original work. After further reflection, and possibly additional experimentation, a formal scientific explanation emerges and connections are made to "real life" experiences of the student.

Case Study: The Experiments of Benjamin Thompson (Count Rumford)

To present an example of a historical representation, I will outline one of Benjamin Thompson's - also known as Count Rumford - experiments on heat which can easily be adapted to the classroom. The case study is summarized in table 1. The first narrative is a brief biography of Rumford and establishes the context of the investigation. Rumford was an "Indiana Jones" kind of guy who led an intriguing life as a soldier, scientist, and spy. Students find the story quite entertaining and the narrative is intended to establish a narrative appetite while setting the scene for the practical exercise to follow by raising the problem Rumford faced to efficiently clothe his military in Bavaria. To make better uniforms, Rumford was interested in determining what materials afforded the best insulating protection. At this point students advance their own ideas and propose and experiment and draw the experimental apparatus to complete the investigation.

The second narrative is an excerpt from Rumford's report of his experiments in the Philosophical Transactions of the Royal Society read February 2, 1804. In this investigation on heat, Rumford built and described in detail a simple set of containers he used to measure the time it would take the container to cool ten degrees. He compared various materials, such as Irish linen and wool, to a standard uncovered container ("naked" in his terminology). Students read his account and then compare and contrast their design and drawings to Rumford's depictions. Invariably many ideas of the students are comparable to Rumford's and a procedure is written to complete the experiments as Rumford did in his lab. In the classroom representation of his experiment, two ordinary soup cans, one naked and the other covered in nylon are cut from women's hosiery. Students are asked to predict how long it takes for each can, naked or covered, to cool ten degrees. Students' predictions are remarkably consistent as they expect the covered can to cool much slower than the naked can. Upon doing the experiment they are surprised that the can dressed in nylon cools faster. Anticipating that they have not performed the experiment correctly, they are even more startled to find their results coincide with Rumford's data!

At this time the third narrative, which is a later excerpt from Rumford's report, is unveiled and students are surprised to find that their results are identical to Rumford's data, the covered can does indeed cool faster than the "naked" can! At this time, hypotheses are reconsidered and modified and these ideas are compared with Rumford's scientific explanation in the fourth excerpt from his report.

Concluding Remarks

Contrary to the prescriptive approach of the typical laboratory manual, students continually generate their own ideas, design an experiment, and write an experimental procedure as they alternate between the narratives and their investigations. As they interact with the narrative throughout the investigation students repeatedly address nature of science questions which arise naturally from the narrative. Students also find it remarkably rewarding that they have similar ideas, design, drawings, and conclusions of the original scientist.

Table 1

Stages of the Historical Narrative	Historical Representation	Student Activity
Context	Narrative Part 1 Brief biography Problem of clothing the military	In your group, devise an experiment to compare the ability of various materials to keep an object warm. Carefully describe your experiment and sketch your proposed apparatus on one page in your notebook.
Experimental Design	Narrative Part 2 Read the first excerpt from Rumford's *"An Enquiry concerning the Nature of Heat, and the Mode of its Communication"* published in the Royal Transactions in 1804.	Complete a chart to compare and contrast your ideas with Rumford's original experiment. In your group, reflect on your original experimental design. Describe any changes that you would make to your experimental design. Using Rumford's notes, write out an experimental procedure for his investigation with the "naked" and "clothed" cans. Record your experimental predictions, expectations, and procedure.
Analysis and Interpretation of Data	Narrative Part 3 Rumford's description of his experiment and apparatus. Performance of Rumford's experiment.	Compare your experimental results to Rumford's results.
Scientific Explanation	Narrative Part 4 Rumford's explanation of the insulating capabilities of air.	How does Rumford account for the discrepant results?

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