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Building a Foundation for the Use of Historical Narratives

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Abstract. Many educators today advocate the use of historical narratives as one of a number of possible contexts for teaching science. However, several pedagogical and epistemological issues arise when implementing narratives in the classroom. In this paper, we are interested in expanding our view of narrative, specific to integrating the history of science and science teaching, and we extend our argument beyond simple anecdotal references to recognise the benefits of the historical narrative in a variety of ways. At the same time, we address pedagogical concerns by broadening perceptions of the manner and contexts in which narratives can be developed so as to include imaginative and manipulative elements that provide interactive experiences for students that are more conducive to implementation by science teachers. Several practical examples are presented as illustrations of historical narratives with imaginative and manipulative elements that by design facilitate a more meaningful implementation in the science classroom.

Key words: narratives, history of science, science education, story

1. Introduction

Millar & Osborne (1998) have expressed the need for a new vision in science education inspired by the inconsistency between “school science” and the needs and interests of students. School science can be characterized by science in its final form (Duschl 1990), that is, scientific knowledge claims, principles, and laws as we know them today without consideration of the historical, social, or philosophical contexts in which these ideas are embedded. Thus, school science taught as Duschl describes is mostly factual knowledge found in textbooks and in this “final form” bears little resemblance to science as it is and has been conducted in research settings. Such decontextualized, textbook-centred teaching is based on the mistaken assumption that learning facts through a set of exemplars is adequate for obtaining an understanding of science. The unrealistic expectations of textbooks are that students can extend their understanding of exemplars to the real world in which they live.

A lasting understanding of science has been shown not to be a consequence of application through common exemplars. We should expect students to develop deeper understandings that allow them to generalize across diverse and relevant connections. To mediate such views of everyday science and "school science", we recommend that teaching science become more contextual such that students can find more meaning and personal relevance in their science education. Millar and Osborne highlight several consequences resonating from the current portrayal of science and the current mode of science education. Some of these consequences include:

- The representation of science as a 'catalogue' of ideas taught independently of the contexts which could provide essential relevance and meaning.
- A lack of emphasis on the significant intellectual achievements of science and how they have influenced understanding ourselves and the world around us.
- An overemphasis on content which limits treatment of other essential components of science such as the nature of science.
- An inability to maintain a sense of wonder and curiosity that many children possess early in their education and rapidly lose as they progress.
- A lack of discussion or analysis of important contemporary issues.
- Too many dull, uninspiring lessons and routine procedures.

There are many ways good teachers of science might address these concerns. In classrooms where science teachers have involved students in the types of inquiry-based lessons and investigatory learning promoted in the National Science Education Standards (CSMEE 2000), students have become more skilled in asking questions; designing, planning, and conducting investigations; gathering, analyzing, and interpreting data; and constructing explanations (Crawford 2000; Keys & Byran 2001; Schillereff 2001; Corry 2005). However, these studies, and others making similar claims, draw attention to the important role of teachers in modeling and scaffolding for students the conceptual and procedural knowledge of scientists (Seatter 2003). What tends to be missing, particularly from the inquiry teaching narratives, is a critique of the perception that scientific inquiry proceeds from statements of observation to statements of theory with little if any attention paid to guiding conceptions (theoretical commitments), and a clarification of the comparison of tentativeness used to describe the changes in the ideas and conceptions of students in the process of learning science with tentativeness associated with speculative ideas (the context of historical discovery) and the occasional discarding of scientific theories by the scientific community (the context of epistemological justification). Moreover, where teachers in the studies cited above are not using an instructional model like the model developed by Monk & Osborne (1997) or the pedagogical practices for teaching "ideas-about-science" that have been identified by Bartholomew et al. (2004), there is little likelihood that students will be given opportunities to think and reason about the processes in which they have been involved or to consider the origin and development of the concepts and phenomena they have investigated or to understand how scientific ideas and knowledge claims came to be justified and accepted with confidence.

An approach to science teaching that incorporates relevant and well-developed components of the history of science can begin to clarify many of these naïve and erroneous beliefs associated with what scientists do and how they know. Such an approach augments traditional teaching by embedding ideas in their original context to make them relevant, acknowledging and appreciating an intellectual tradition, providing a natural avenue to raise nature of science questions, and the presentation of a non-routine, humanistic perspective many students finding appealing (Metz 2003).

Millar and Osborne also propose "the use of the narrative form" in communicating ideas and making these ideas coherent, memorable, and meaningful". They further suggest that a historical perspective is one of the ways in which the narrative form may be utilized. The historical narrative has long been demonstrated to be capable of providing a context to address science content in a humanistic and more authentic manner (Conant 1957; Klopfer & Cooley 1963; Solomon et al. 1992; Matthews 1994; Stinner 1995; Hagen et al. 1996; Clough 1997, 2004, 2006; Kubli 1998; Irwin 2000; Stinner et al. 2003, and many others).

Historical narratives when sensitively constructed naturally include a humanizing element that raises personal, ethical, sociological, philosophical and political concerns which tend to increase interest and motivation in students (Meyling 1997; Metz 2003). In this paper we propose to review some of the existing literature on the nature of narratives with a particular focus on the roles of the teacher and science learner in the implementation of a narrative approach in the classroom.

2. Understanding Narrative

In the broadest sense, narrative may be defined as "anything that tells a story, in whatever genre" (Jahn 2001, par. N1.1) or "telling someone else that something happened" (Herrenstein-Smith 1981, p. 228). Recently, Norris et al. (2005) elaborated on Herrenstein-Smith's uncomplicated view of narrative to identify the roles of the narrator, the reader, events, and past time. According to Norris et al. the narrator is the agent who is telling the story and determines its purpose by choosing the events and the order in which they are related. The receiver is the reader (in the case of written material) who interprets the text while events are the experiences of the agents of the narrative connected and related through time.

Norris and colleagues also outline narrative elements, such as narrative appetite, structure, agency, and purpose, which are considered to be essential components for advancing to narrative beyond simple expository text. Of particular interest to this paper is narrative appetite described as "the desire created in readers and listeners to know what will happen", and the purpose of narratives that the authors maintain is "to help us imagine and feel the experience of others".

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". In their theoretical model the authors argue that in the absence of narrative elements the learner is unlikely to interpret the narrative as a viable explanation. Consequently, in this situation, the learner will not assimilate the positive effects of memorable learning and comprehension generally associated with narratives.

We believe that to employ narrative as an explanatory device more attention needs to be focused on the roles of the teacher and learner during the implementation of the narration. For historical narratives to be successfully implemented, we advocate the use of imaginative and manipulative components within the narrative. By manipulative we do not just mean investigative or laboratory-like experiences but rather the manipulation of ideas through some action that involves the reader in an ongoing interaction with the narrative. Moreover, we believe that an imaginative and manipulative interaction with the narrative is necessary if students are to have some degree of choice in their learning. Mediation by the narrator is necessary so that events are not merely recounted. The narrator has a responsibility to facilitate the interpretation of the events in a contextual manner. We suggest that there are many ways to accomplish this goal. These include, but are not limited to, the use of story, insight into literary devices and storytelling, historical representations, thematic approaches, storylines, and large context problems (Stinner et al. 2003).

3. Narrative Forms

Narrative is a rhetorical mode that has as its core purpose the recounting of related events. In particular, historical narratives present humanistic episodes that can be used to generate student interest and motivation (Solomon 2002). Various scholars have used the terms "narrative" (Martin & Brouwer 1991; Kubli 1998), "story" (Egan 1989; Kenealy 1989; Stinner 1995; Kubli 1999), "thematic" (Holbrow et al. 1995) or "storyline" (Arons 1988; Stinner 1995; Coleman & Griffith 1997) to describe different contextual approaches. The narrative approach has a spectrum of possible applications, ranging from the smallest stand-alone story element such as the vignette (Wandersee 1992) or anecdote (Shrigley & Koballa 1989), to the largest story-like structure such as the curriculum unit unified by a theme (Holbrow et al. 1995; Gorman & Robinson 1998) or storyline (Coleman & Griffiths 1997; Stinner & Williams 1998). The story and storyline will be our focus here.

3.1. STORY

In our experience, most students when asked to recall their school science experience readily refer to the Eureka! experiences narrated in texts. The tale of Archimedes' bath, the apple falling on Newton's head, or the experiments of Galileo atop the Leaning Tower of Pisa, are examples even the most uninterested science student easily recounts. While seemingly trite, and often untrue, these vignettes of history suit certain pedagogical needs as we initially try to attract students' attention.

Story, although a type of narrative, has a more restrictive meaning than narrative and might be defined as "a sequence of events and actions involving characters" (Jahn 2001, par. N1.1). A key element considered by most story theorists as essential is the requirement that events of the story be chronological. A story must also contain plot, which adds a causal or intentional element relating the incidents of the story (Prince 1973; Egan 1978). It is these two elements of the narrative, and the story form in particular, that make it so well suited to the presentation of historical material.

Using the work of Scholes, Milne (1996) presents the structure of a story as a semiotic circle of events, text, and interpretation. In this view, a story is a set of events sequenced in time. These events are converted into text and in the process the author imposes meanings and values on the events. As the text is read or listened to, the audience interprets it idiosyncratically. Often the interpretations are an attempt to reconstitute the original set of events. Even though the terms narrative and story are often used interchangeably, Milne believes that the stories' focus is on the values and meaning in the presentation and interpretation of the selected events.

Stories can be used in various ways in science lessons. One way is what Kubli (2005) calls "door openers" for science lessons. Such stories should be relatively short and to the point. Stories to be used as door openers do not have as their primary purpose the explanatory function (Norris et al. 2005) but they are intended to make the concept being taught more memorable, to help reduce the distance between teacher and students, and to assist in illuminating a particular point being made (Kubli, 2005). Door opening science stories provide "reasons for needing to know". Another, perhaps more significant purpose behind such stories is to raise questions or leave the student with unresolved problems or issues which form a significant part of the science material being taught. Depending on the maturity level of the student and the amount of time available, the teacher may provide more or less guidance for students in formulating such questions.

While we advocate the use of story, other writers remind us of the need to be cautious in our approach (Milne 1996; Allchin 2003). In his critique of historical narratives in science education, Allchin (2003) encourages us to re-examine the popular portrayal of science and scientists. He argues that historical stories used in science education today employ an "architecture of myth". This architecture dramatizes an oversimplification of science and scientists and serves a function of explaining and justifying the authority of science. In this mythical approach, the popular histories of science romanticize scientists – "Their personality exudes virtue. They exhibit no character flaws" – and we inflate the drama of their discoveries casting scientists and the process of science out of proportion. Thus, the consequence of focussing on telling a good story is a distorted history and nature of science.

Allchin also advises that the historical narrative, as it is used today, conflates the nature of science into an "all too familiar just-so story of "How Science Finds the Truth". He concludes that we do not need more history in science education. Rather, we need different types of history that convey the nature of science more effectively. That is, Allchin claims that simply employing vignettes is not sufficient if we are merely trading or using history for dramatic effect. Allchin further claims that story can be easily set adrift by the overuse of literary technique that innocently intends to make a story more interesting and memorable to the student. He argues that the literary craft through various rhetorical devices such as vindication, tragic irony, and the eureka moment perpetuates "myths" which are a misleading representation of science.

Although we recognize the problems of oversimplification and the limitations of the heroic tale, Allchin's view may be somewhat overstated. First, where there is no history we may certainly need more history. Further, we must recognize that in creating historical narratives for science education, a tension naturally exist between accurately reporting all details in the historical development of ideas and efforts to accurately convey the nature of science and scientists without transforming science courses into history of science courses. We believe that there is a difference between employing literary devices in a misleading way and their use in an intellectually honest manner. Literary devices such as plot, irony, or creating bipolar opposites can be used to develop a narrative appetite, however, it is not likely that such interest and motivation can be expected from the reader alone. The act of storytelling becomes essential in conveying the unfolding of the narrative in a meaningful manner.

One interesting approach to storytelling is the "punctuated" or interrupted story form (Roach & Wandersee 1993). In the interrupted story form, the vignette is broken down into smaller units from which students have the opportunity to make inferences and predictions. This leads us to consider the juxtaposition of several vignettes in the formation of a thematic or storyline approach to narrative.

3.2. STORYLINE

The thematic or storyline approaches are more difficult to characterize. Their advocates and practitioners only vaguely and generally describe the defining characteristics, and it appears that no precise definitions for these approaches exist within the educational literature. The theme of a narrative is commonly thought of as the topic, proposition, or underlying idea that forms the basis or motivation for the narrative. Often the thematic approach will begin with a "big question" such as "Why do we believe in atoms and their properties?" with the answer contained in a running presentation of related historical episodes. In this respect there does not appear to be a large difference from the storyline approach, which is based on "one unifying central idea that attracts the imagination of students" (Stinner & Williams 1998, p. 1030). The term "storyline" is almost nowhere discussed by itself, although in common literary usage it refers to the sequence of related events comprising the story, devoid of the characters' motivations. Science education literature, however, seems not to distinguish between the words "thematic" and "storyline" when describing a narrative approach. Here the "unifying central idea" of the storyline is essentially viewed as the theme. Furthermore, the term "storyline" in science education can be used to describe either an instructional approach or a type of narrative structure. At best, one could formulate a definition for the *science* storyline, which lends itself to the use of history of science, as *a loosely-knit set of chronological episodes taken from the history of science, related either by the characters involved or the theme. These episodes provide coherence for the study of a topic.* The science storyline, however, is different from the literary storyline in that the literary storyline is the "skeleton" of a story whereas the science storyline is a collection of episodes that could *contain* stories which stand on their own. The science story is a tightly-knit set of episodes that must be presented or read in one sitting, whereas the science storyline is a loosely-knit set of episodes that may be presented or read in a series of sittings.

Of special interest here is the large context problem (LCP) as defined by Stinner (1985, 1990). The LCP seeks to present instructional concepts in contexts as close to eventual transfer situations as possible. The LCP belongs to the class of storyline approaches, but may employ other narrative techniques within its scope. For example, stories may be a part of the LCP as door openers in order to present the human side of the historical situation employed by the LCP. The historical situation, perhaps presented as a science storyline, gives rise to various interesting science problems to be considered and solved by students. Invariably, students find LCP's significantly more interesting and motivating than traditional lectures, cookbook-style labs, end-of chapter problems, or take-home assignments (Stinner 1995).

The storyline and large context problems are ideally suited to the interrupted or punctuated story form. In storytelling, the narrator provides multiple access points through mediation to students facilitating a meaningful interaction between the student and the narrative.

4. Mediation

Phillips and Norris' (1999) study with students who read popular reports of science found that the majority of students deferred to the arguments of the reports by implicitly trusting the authors. Any student who changed their certainty about their beliefs did so by deferring to the authority of the author or by merely recanting the contents of the text. The results of this research illustrate that most students left to their own designs will not adopt a critical stance to their reading. Consequently, we cannot expect students on their own to develop a critical stance towards narrative; thus, mediation to guide students through a process of critical analysis should be an essential component of the narrative process.

Any meaning derived from text will depend on the background knowledge of the reader and the social context in which the narrative occurs. Thus, we argue that strategies for implementing narratives should be considered as a necessary condition for meaningful use of narrative. Strategies for mediation should be present before, during, and after the narrative for maximum effect. Some suggestions that we offer include:

- Activate prior knowledge through activities that capture student interest and connect students' background with the story details. This can be done within or independently of the story.

- Use an interrupted story approach to enable students to make inferences and predictions
- Solicit individual and/or group reactions while asking open-ended questions.
- Employ compare and contrast strategies that relate student ideas to the historical ones.
- Provide for related demonstrations and experiments, projects and research, and cross-curricular integration.
- Use writing activities such as a log or journal, for reflections and question generation.
- Use guided reading strategies such as issue-based analysis or paired reading (Moore & Bintz 2002).

Additionally, special attention needs to be paid to the use of historical narrative to promote an understanding of the nature of science (NOS). Even when accurate historical materials are used, students' prior ideas regarding science content and the NOS will play a large role in their efforts to make sense of those experiences. Because most students' prior notions of the NOS are filled with misconceptions, they will likely attend to aspects of stories that fit their prior ideas, unknowingly modify other aspects to fit their prior ideas, and ignore other aspects that do not fit their prior understandings (Abd-El-Khalick & Lederman 2000; Tao, 2003). Students interpreting science stories in idiosyncratic ways, and focusing on aspects of stories that fit their NOS misconceptions was noted in a study by Tao (2003):

> Since most students drew on the science stories for justifications of their views, the way they interpreted the science stories was crucial. Students' peer interactions showed that most of them were not fully aware of the overall theme of the stories; instead they attended to certain aspects that appealed to them and appeared to confirm and reinforce their inadequate views. (p. 167)

Using a theoretical framework of how people learn, Clough (2006) argues that effective NOS instruction requires a number of conditions including connections to the actual workings of scientists. He writes that while short science stories are an important way for teaching about the NOS, they must be carefully crafted and used with the following guidelines:

1. A tight link should exist between the fundamental science content and targeted NOS ideas in the short stories so that teachers do not feel they are neglecting the former in promoting the latter – the most significant reason science teachers give for not accurately addressing the NOS;
2. Science teachers must be able to use the short stories when and where they deem appropriate;

3. Short stories should address both historical and contemporary instances so that students cannot easily dismiss past events by attributing them to wrong thinking that has now been corrected;
4. Wherever appropriate, the voice of scientists should be used to provide authenticity to the NOS point(s) being emphasized;
5. The short stories must include comments and questions that draw students' attention to more accurate ideas regarding the NOS; and
6. The short stories must be carefully scaffolded to students' science experiences in and out of the science classroom.

5. Case Studies

To conclude, we provide four case studies for illustrating the implementation of the historical narrative in a science classroom. These examples cover a wide range of age groups and illustrate the potential for using the historical narrative more successfully.

5.1. THE USE OF STORIES IN SCIENCE AS DOOR OPENERS

Lessons incorporating stories from the history of science should be designed in such a way as to raise questions, naturally. The material for such stories is not necessarily easy to locate. A brief case study of the writing of such a story and its subsequent use by one of the authors (Klassen) is presented below. The context chosen is a second-year university physics laboratory class with the topic of the absorption of radiation by various materials.

The topic had previously been taught in a didactic, de-contextualized fashion, and the laboratory had been approached in a cookbook style, typical of teaching that has not yet been re-designed to reflect sound research and scholarship-based pedagogy. The laboratory exercise revolved around determining the value of the absorption coefficient of a material, without linking it to the purpose of radiation protection, which provides "a reason for needing to know" the radiation absorption properties of materials. The strategy selected for re-designing the lesson was to use a story to make the linkage between the pedagogical experiment and its purpose more explicit. It was postulated that student engagement could be enhanced by linking the experiment to events that pre-date radiation protection awareness thereby producing a dramatic contrast with current knowledge and practice. The material for just such a story was discovered in the documentary movie "Tickling the Dragon's Tail: The Story of Louis Slotin" (32). The story deals with a Winnipeg-born and educated scientist, Dr. Louis Slotin, who distinguished himself in the 1940's by assembling the first atomic bomb. The story, cast in the form of fictionalized history, may be read online at our website http://www.sci-ed.ca. During his work, Slotin had been exposed to 21 Sieverts of radiation in an instant as the bomb became supercritical when the top half came completely in contact with the bottom. His quick reaction in using his bare hands to pull apart the two halves of the bomb shell saved the lives of everyone else in the room that day, May 12, 1946. Eighteen days later, Slotin died an excruciating death from extreme radiation exposure. Everyone considered Slotin a hero. If the science of radiation protection had already been developed by 1946, then this true story would likely never have taken place.

The Slotin story illustrates a number of important narrative features as discussed above. The story creates in the listeners or readers the desire to know what will happen to Slotin and gives them access to Slotin's experiences and (supposed) thoughts, thereby allowing them to imagine what Slotin's ordeal was like. These features, together, produce narrative appetite in the listener or reader. As an introduction to a lesson, the story becomes a "door-opener" to the idea of radiation protection, explicitly providing a "reason for needing to know" about the absorption of radiation by various materials. The story should provide an incentive to students to raise a number of questions that they consider interesting and important. The teacher, in turn, has the responsibility to "mediate" between students' initial responses to the story and the desired instructional goals.

In the course of implementing the re-designed lesson, Klassen found that most students independently recognized the importance of the science of radiation protection as the main point in the Slotin story. When students were given the opportunity to respond to the story, they raised historical, personal, scientific, and ethical questions. In order to mediate between initial student ideas and the target concepts, the instructor introduced students to additional questions like the following:

- Are all levels of radiation exposure dangerous?
- What is my cancer risk from radiation exposure?
- What are the current regulations for radiation exposure?
- What is the basis of radiation protection?

Exploration of questions such as these was followed by an experimental investigation of radiation shielding, which is a measure that can be taken for protection against exposure. An alternative or additional experiment could investigate the effect of distance from the radioactive source. In some teaching facilities, the equipment for this will not be available. Plans are underway to place a realistic simulation of the equipment and its operation on a webpage so that students without access to radioactive sources and counting equipment may experience that type of activity, albeit vicariously. Follow-up problems naturally arise from the investigation, for example, having students estimate the personal exposure dose of radiation they received while doing the investigation and rating it against the protection standards. The reader should be assured that such activities remain within accepted standards of risk by a wide margin.

5.2. STORY FROM PERSONAL NARRATIVE

Teachers of young children between the ages of 5 and 13 often use stories found in children's literature as contexts for first-hand investigations and inquiries in science (Frost 1997; Glandon, 2000; Stout 2001; Flagg & Ory 2002; Ansberry & Morgan 2005; Royce & Wiley 2005; Ford 2006). A few of these stories have been written about scientists and engineers. An even smaller number portray incidents from the history of science in story form. Rarely do such abbreviated biographies and histories contain information sufficient for teachers at the elementary level to develop case studies as described in this paper, or to help children to develop the knowledge and inquiry skills such integrated and storyline approaches help to cultivate (Gorman & Robinson 1998; Metz 2002). As a result, attempts are seldom made by teachers, in the limited time they have available for science teaching, to "connect the development of individual thinking with the development of scientific ideas", to use the story to promote "the better comprehension of scientific concepts and scientific methods", or to develop an understanding of the nature of science – three of the seven reasons listed by Matthews (1994, p. 50) for including the history of science in science teaching.

If the three items on Matthew's list are general outcomes that science lessons should be designed to achieve, the science stories that elementary teachers tell should, on occasion, allow an image of science and the scientist to be constructed from scientists' ideas and their questions, investigations, and conclusions. The stories must be historically accurate, as previously stated and, in the case of learners at the elementary school level, developmentally appropriate. One approach for creating such stories or storylines is to include the personal documents and manuscripts of a particular scientist along with relevant biographical materials and publications, where necessary. The narratives should be developed so that specific learning outcomes are not simply addressed through reading or listening. They are achieved as a consequence of finding answers to the questions the selected materials generate and because of the perspectives and/or procedures represented in the materials that learners are asked to think about and apply. One example, currently being developed for Grade 6, is the scientific work of Beatrix Potter (1866--1943), an author--illustrator of children's literature whose Peter Rabbit, Hunca Munca, and Squirrel Nutkin are recognized by readers of all ages. Potter's mycological work, unknown to many who are intimately aware of her "little books", is an especially interesting context in which to teach and learn about the diversity and classification of living organisms (one of four units in the Manitoba Grade 6 science curriculum), and to become aware of the difficulties encountered when new evidence contradicts what is collectively believed by the scientific community.

Between 1888 and 1901, Potter painted over 250 species of fungi[1] in more than 335 watercolours (Watling 2001) that represented most of the major groups of macrofungi (Schmid 1999). She kept a journal written in her own privately invented code from about the age of 14 through the first half of her 30th year (Linder 1989). In addition, she was a prolific letter writer her entire adult life (Taylor 1989, 1992). When relevant illustrations, like those of the basidiomycetes (toadstools) and germinating spores of 40–50 different fungal species, are arranged chronologically with pertinent transcriptions of her journal entries and related correspondence with individuals like her Uncle Harry[2], William Thiselton-Dyer,[3] and Charles McIntosh,[4] it's possible to trace the development of her scientific ideas and her evolution as a pioneering mycologist/lichenologist.

Rather than sorting buttons, tools, or shoes to make a classification scheme or developing a dichotomous key for several species of aliens, children exposed to Potter's story will learn about a kingdom of organisms rarely addressed beyond the concepts of decomposition, fermentation, and infection. Moreover, they become aware of these organisms in their local environment and learn about fungi as Potter herself did. The story begins with the Scottish highland folklore associated with the woodland faeries and fairy rings that were told to young Potter by her nanny. These myths are followed by experiences that develop an aesthetic appreciation for the forms, structure, and colours of the basidiomycetes while studying Potter's watercolours paintings and reproducing pictorially what is observed in nature and displayed in the classroom. This section of the story which focuses on Potter's romantic engagement with fungi (see Whitehead 1929) is followed by the stage of precision in her self-directed education. Children, with a mycologist as mentor, like Potter in her relationship with McIntosh, learn about the distinguishing, observable characteristics used in the scientific naming, classifying, and illustrating of fungi in the late 1800s. They then attempt to reproduce Potter's microscopic investigations of spore germination that eventually led her, as "an amateur", to challenge the taxonomic system of the time, particularly the problem of hybrid species and the fungus and alga of the lichen symbiosis. Finally, children will use the writing and correspondence of Potter along with bibliographic information to try to explain her decision to direct time and energy into less discriminatory and more lucrative endeavours when her paper, "On the Germination of Spores of Agaricineae", was presented by Mr. George Massee[5] to the Linnean Society of London on 01 April 1897. It is believed to have received a lukewarm reception from the established university educated scientists in attendance, and was withdrawn before publication at Potter's request (Clegg 1987).

In an approach such as this, three of the types of explanation characterized by Norris and colleagues (2005) are inherent components of the storyline (e.g. interpretive, justificatory, descriptive). For running through the narrative are the questions, what is a plant, where do fungi fit into the classification of organisms, what is a lichen, and who determines the answers to questions such as these. Among other outcomes, students will come to understand the controversial history that surrounds contemporary biological definitions of symbiosis and lichen and recognize how inadequately this rich history is represented with a textbook definition and example.

5.3. PRACTICAL WORK AND THE INTERUPTED STORYLINE

In the lecture-laboratory style of instruction, the laboratory activity illustrates the information outlined in the classroom lecture (Yager 1992). 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 all to common teaching style, which is exemplified in most laboratory manuals, emphasizes the verification of scientific laws and is restricted in its engagement of students in an imaginative manner. The approach itself is limited in its portrayal of the scientific method and focuses on apparatus not ideas. In other words, students merely connect the dots without purpose (other than to produce data) and without reflection on the essential ideas inherent in the tasks. There is also a notable lack of "needing to know", as students often know the answer before they begin the exercise.

One possible way of addressing these limitations is to provide students with the opportunity to use their imagination through a parallel process in which they manipulate ideas as well as physical objects. Representing experiments historically through the use of a narrative initiates a process that enables students to reflect upon the nature of the experiment in addition to the context in which the experiment was originally performed.

The replication of historical experiments has been recommended by several historians and science educators (Mathews 1994; Reiß 1995; Kipnis 1996; Heering 2003). Building on Heering's (2003) historical replication methodology we have developed several historical representations which are practical activities for students based on historical experiments. Our historical representations use a alternative approach to laboratory investigations that incorporates historical narratives in an interrupted story form to permit students to move between ideas and investigations. The intent is to direct students to manipulate ideas in addition to physical objects.

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, which is unveiled to students throughout the investigation. The use of original materials permits students to compare their ideas to the original experimenter as the narrative is revealed in many parts. Students make predictions, raise questions, and compare their ideas for experimental apparatus, methods, and data analysis to original authors. In this way, students often find their ideas parallel in some ways the thoughts of famous scientists.

As it relates to the investigation, the narrative used in the investigation contains four parts;

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

The introductory segment of the narrative establishes a context with the inclusion of biographical and cultural information while raising a problem and/or confrontation. Research indicates that stories about scientists' personal lives can improve students' image of science and scientists (Seker 2003) and that students reflect positively on ideas of early scientists (Metz 2003). Students can research this introduction themselves, or it can be written and presented directly by the teacher. The narrative is initially used to activate students' prior knowledge and 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 that 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.

An example of a historical representation is Benjamin Thompson's (Count Rumford) experiments on heat which can easily be adapted to the classroom. The four parts of the narrative are extracted directly from Rumford's "*An Enquiry concerning the Nature of Heat, and the Mode of its Communication*" published in 1804 in the Philosophical Transactions of the Royal Society. In these investigations, Rumford was interested in determining what materials afforded the best insulating protection. He built a simple container and measured the time it would take the container to cool ten degrees. Rumford compared various materials, such as Irish linen and wool, to a standard uncovered container ("naked" in his terminology). Students read portions of Rumford's written description of his experiment and then consider their own ideas. For example, 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!

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

5.4. SHORT STORIES AND THE NATURE OF SCIENCE

Clough & Olson (2004) write about efforts they and their colleagues are making to create science short stories that address the development of fundamental science ideas, and assess the effect of the short stories on students' understanding of the NOS and science content. Each story targets the development of a fundamental science idea and seeks to create an appetite among readers to understand how the particular scientific controversy was resolved. Each story's purpose is to teach science content and help students better understand the personal and professional life of scientists and what doing authentic science is like. Seriously considering the evidence and arguments put forward by scientists, readers will more likely understand the fundamental science idea targeted in the short story and how science works.

The content and structure of the short stories, particularly the use of scientists' voices, set a stage for understanding the NOS in ways other approaches cannot. However, as with any curricular materials, teachers' enthusiasm, the importance they place on deeply understanding the NOS and science content, and how they link the short stories to other experiences will significantly impact student engagement. For this reason, the historical short stories project also provides content and pedagogical support to teachers so that they are more likely to effectively implement the short stories.

The following are three excerpts and embedded questions from a historical short story about determining the structure of DNA.

Excerpt 1: In the 1940s most scientists thought that the genetic material would be made up of protein. Several reasons supported this contention.... However, work by Avery, MacLeod, and McCarty in 1944 was interpreted by many scientists to mean that deoxyribonucleic Acid (DNA), not protein, was the genetic material.... Not all scientists agreed with this interpretation of the evidence:

Of course there were scientists who thought the evidence favoring DNA was inconclusive and preferred to believe that genes were protein molecules. Francis, however, did not worry about these sceptics. Many were cantankerous fools who unfailingly backed the wrong horses. One could not be a successful scientist without realizing that, in contrast to the popular conceptions supported by newspapers and mothers of scientists, a goodly number of scientists are not only narrow-minded and dull, but also just stupid. (Watson, 1968, p. 13)

Watson admitted that further experimental work was needed to show that all genes are composed of DNA, and additional evidence for DNA being the genetic material was reported by Hershey and Chase in 1952. However, Watson and Crick (and other scientists) were already engaged in efforts to determine the structure of DNA before this work was reported; confident DNA was the genetic material.

Question: What does this disagreement among scientists illustrate about interpreting experimental data?

Excerpt 2: Watson spent considerable time trying to make a like-with-like (i.e. cytosine paired with cytosine, guanine with guanine, thymine with thymine, and adenine with adenine) double stranded DNA structure work. However, he acknowledged that the difference in sizes between the pyrimidines and purines meant the sugar phosphate backbone would have a quite irregular width. Crick also worried that Watson's like-with-like idea did not account for Chargaff's rule (the amount of adenine in an organism equals the amount of thymine, and the amount of cytosine equals the amount of guanine.). Interestingly, Watson professed not to have much faith in Chargaff's experimental work. Although Watson continued to work with his like-with-like idea, he eventually began entertaining other possibilities.

Question: Note that Watson did not give up easily on his earlier idea despite the evidence against it. Why might this be the case with him, or any scientist? What does this illustrate about individual scientist's objectivity?

Excerpt 3: Later, while trying different arrangements of the purine and pyrimidine base pairs, Watson became aware that an adenine–thymine pair was identical in shape to a guanine–cytosine pair. He wrote, "my morale skyrocketed, for I suspected that we now had the answer to the riddle of why the number of purine residues exactly equaled the number of pyrimidine residues. Chargaff's rule then suddenly stood out as a consequence of a double-helical structure for DNA."

Question: Earlier Watson spoke poorly of scientists who did not accept the evidence for DNA being the genetic material. Yet Watson was resistant to accept Chargaff's experimental evidence. Why do you think Watson changed his mind about Chargaff's work? How does this story illustrate that scientific data does not tell scientists what to think?

6. Concluding Remarks

We have illustrated several ways to expand the view of narrative including stories as door openers, storylines, interrupted story forms, personal narratives and short stories that are conducive to integrating the history and nature of science and science teaching. By broadening perceptions of the manner and contexts in which narratives can be used we are able to include imaginative and manipulative elements that provide interactive experiences for students. In this way we have found that the development of such historical narratives facilitate a more meaningful implementation in the science classroom.

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Notes

[1] Potter intended to use her paintings to illustrate in a book on fungi (Clegg 1989). In a letter posted on March 6th 1897 to Walter Gaddum, Potter's nine-year-old second cousin, she wrote the following: "I have been drawing funguses very hard, I think some day they will be put in a book but it will be a dull one to read" (Taylor 1992, p. 100). In 1967, fifty-nine of Potter's illustrations were published in

W.P.K. Findlay's (mycologist and past President of the British Mycological Society) "Wayside and Woodland Fungi", a field guide to the fungi and lichens of the British Isles (Findlay, 1969).

[2] Sir Henry E. Roscoe, F.R.S. (1833–1915) a distinguished chemist known for his work in photochemistry with Robert Bunsen, University of Heidelberg and the isolation of vanadium and study of vanadium compounds (The Columbia Electronic Encyclopedia, 6th ed. Retrieved July 01, 2005 from http://www.infoplease.com/ce6/people/A0842403.html.

[3] (1843–1928) Assistant director of the Royal Botanical Gardens at Kew under Sir Joseph Hooker form 1875 until1885. Appointed Director of Kew in 1885; retiring from this post in December 1905. Kew, History & Heritage: William Turner Thistleton-Dyer. Retrieved July 01, 2005 from http://www.rbgkew.org.uk/heritage/people/thiselton_dyer.html.

[4] (1839–1922) A postman, published naturalist, and elected Associate of the Perthshire Society of Natural Sciences who was Potter's mentor and collaborator from 1892 to 1897 (Battrick 1999; Linder 1989).

[5] Massee was a Yorkshire mycologist working at the Royal Botanical Gardens, Kew. Potter met him on several occasions between 1896 and 1897. He used her culturing techniques to germinate some of her "best moulds" [spores] (Potter, 1897, in Linder 1989, p.441).

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