The Episodic Historical Narrative as a Structure to Guide Inquiry in Science and Nature of Science Education

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Abstract. Inquiry learning is ideally open-ended and student-directed. Yet from a teacher's pragmatic perspective of managing instruction in classroom settings, both features may be problematic. History—when framed from a historical perspective as science in the making—can provide occasions for authentic inquiry questions. It can also provide a predictable trajectory for guiding students through a coherent series of planned inquiry activities, without upsetting the uncertainty and open-endedness at each stage. Ultimately, students may reflect on their own inquiry solutions, and compare them with history to help them understand scientific practices, or the nature of science. This paper describes several features in how episodic historical narratives may structure such guided inquiry.

Introduction

Science educators now generally recognize three ways to teach about the nature of science (NOS) or scientific practices: through reflective student-led inquiry, contemporary cases, and historical cases. Recently, Deng et al. (2011) claimed that inquiry seems uniformly important (a view largely echoed by the U.S. National Research Council [Committee on Conceptual Framework, 2012]). Yet each of the three approaches exhibits intrinsic merits and deficits. They are best viewed as complementary. The challenge now is for educators to explore how to integrate them fruitfully in the classroom (Allchin, Andersen & Nielsen, 2014). This paper addresses this challenge in part, describing how student inquiry may be combined with history of science towards achieving NOS understanding. The model, informed both by research and by teaching practice, is basically to situate students in a historical context of science-in-the-making (Latour, 1987), while using a historical trajectory to guide students through successive inquiry activities.

At first, it may seem that NOS lessons from history, based on understanding a closed episode of inquiry from the past, are incompatible with inquiry, which is fundamentally open-ended. Student inquiry fosters student learning about the process of science by helping them investigate problems on their own. Like the genuine knowledge-building efforts of science which it hopes to model, it is open-ended. Inquiry learning proceeds blind to the outcome. It responds opportunistically to context and unanticipated factors. It is thus hard to predict in advance where it may lead. The emotion of that lively adventure, with its uncertain trajectory and ultimate thrill of discovery, is partly why inquiry lessons are effective.

Science educators (along with philosophers of science) recognize that history, too, can yield potent lessons about the nature of science (Klopfer & Cooley, 1963; Teixeira, Greca & Friere, 2012). But historical understanding is achieved chiefly through retrospective analysis, rather than real-time experience. The stories of famous scientists or notable discoveries in the past also once exhibited the same unknowns and problem-solving methods, but the key events have already occurred. One studies and reflects on them from a privileged position of a stable answer being known. History would thus seems ripe for descriptive, expository or explanatory accounts of the process of science for students (Clough, 2011; Conant and Nash, 1957; Klassen, 2009; Metz, Klassen, McMillan, Clough & Olson, 2007).

However, one may ask whether, or how, one might benefit from both history, with its definitive retrospective view of firmly constructed science, and inquiry, with its uncertain immersive view of science-in-the-making, at the same time (Henke & Höttecke, 2012; HIPST, 2008). In what ways might history valuably contribute to student inquiry cases? Likewise, in what ways can student inquiry approaches help in conveying the NOS lessons latent in history? This is the challenge addressed here.

Science educators to date have explored many ways of coupling history with inquiry or student investigative activities (Table 1). Each exhibits an implicit relationship between history and inquiry. Some merely interleave historical context with decontextualized or contemporary student activities, with little interaction. Others endeavor to situtate students more fully in a historical setting, sometimes having them begin with outmoded theoretical perspectives and/or use historical instruments. The alternative described here adopts another form of integration, aimed to address the central principles of learning theory, as well as typical classroom challenges. The accompanying discussion also helps to justify and structure the use of history in science education, in parallel to the proposal by Monk and Osborne (1997). Students are invited to address *historical problems* or *questions*, experiencing the openness of science-in-the-making (Allchin, 2012; 2013, pp. 39-44; Hagen, Allchin & Singer, 1996; Rudge & Howe, 2009). This uncertainty allows for fundamental inquiry lessons about how scientific knowledge is constructed from observations, analogy, creative thought, evidence, material resources and communal discourse. But there is no intent for students to formally recapitulate actual history. Still, the history is a valuable benchmark, when introduced after student work. Comparison helps students analyze, assess, and reflect on their own efforts, as well as interpret those of history (Howe, 2007; Monk & Osborne, 1997). The role of history is to motivate student inquiry, frame problems, illustrate scientists at work, and (for instructors) provide an investigative trajectory that ultimately reaches a known (modern) solution and stable closure to the inquiry.

The solution profiled here is thus to frame a *guided* or partly structured inquiry using a historical narrative as a backbone, as exemplified in two large sets of historical case studies now available online (Allchin, 2012; Hagen, Allchin & Singer, 1996). By adopting historical perspectives and framing events as science-in-the-making, one can create an authentic and humanistic context for inquiry questions. Earlier historical case studies for science education, such as those developed by James Bryant Conant and Leonard Nash in the 1950s (Conant and Nash, 1957), presented students with discovery narratives. But they did not pose questions to engage students in their own problem-solving and thinking. They did not problematize the nature of scientific work. According to the constructivist instructional principles generally accepted today (Driver & Oldham, 1985), the earlier case histories did not actively engage students in their own learning, or invite them to reflect explicitly about how scientific knowledge develops. In the model profiled here, by contrast, the narrative focuses on key historical moments where one can pose questions or decisions to students, and invite their participation. That is, one transforms the unfolding history into a series of succcesive occasions for inquiry learning, about both science and nature of science. Several features of an episodic historical narrative seem important to fostering such learning. These are detailed in the sections below. In particular, historical cases designed to structure inquiry differ significantly other uses of history and storytelling in science education, already described.

Table 1. Sample efforts to integrate history of science and student inquiry.

Lesson type/relationship between history and student inquiry	*Examples*	*References*
Student as historical inquirer	• Students work on historical apparatus replicas to study classical physics in historical context.	Reiß (1995)
Student as inquirer in historical problem-space	• Students collect William Harvey's observations on blood flow, then reason from them to "rediscover" circulation	Allchin (1993)
Student as inquirer contextualized in a historical scenario	• Students follow Anthony Allison in his investigations of sickle cell anemia	Howe (2011)
	• Students follow Alfred Wallace in trying to how new species originate.	Friedman (2011)
	• Students follow a series of investigators of snowflake formation.	McMillan (2012)
	• Students follow Charles Keeling as he measures atmospheric carbon dioxide.	Leaf (2012)
	• Students role-play Galileo's trial in 1633 or a Presidential committee in 1963 assessing Rachel Carson's *Silent Spring*.	Allchin (2013, pp. 202-240)
Student as modern inquirer, but also addressing historical ideas	• Students invesitgate how plants grow, learning about van Helmont's ideas before their own testing	Monk & Osborne (1997)
Student as modern analogical inquirer	• Students use a modern gnomon to mimick Copernicus's mapping of solar position	Czerwińska (2010)
	• Students draw and classify fish, as King Carlos of Portugal did.	Faria, Pereira & Chagas (2012)
	• Students classify palm trees, as Alfred Wallace did in the Amazon.	Prestes & Souza, this volume

As noted, this model of historically based inquiry has guided the development of over 3 dozen case studies. One case in particular, on investigating the cause of beriberi in the late 1890s (Allchin, 2013b, pp. 165-183), will be used throughout this paper to help illustrate the general features of the model.[1] In this case, students follow the work of Christian Eijkman, who eventually earned a Nobel Prize. At many points in the narrative, they address authentic questions: about orienting research, interpreting experimental results, responding to chance events, reflecting on human experimental subjects, assessing the burden of proof, and so on, leading to several lessons about the nature of science.

History & the Problem of Inquiry

To begin, consider some fundamental problems for teachers in managing student inquiry in the classroom. Inquiry learning is now generally accepted as an educational ideal, based on constructivist principles of student-centered learning and active learning (Deng et al., 2011; Driver & Oldham, 1985; Duschl and Grandy, 2008). By helping students tackle problems on their own, inquiry fosters learning about the process of science. Yet like all genuine investigative efforts, which it hopes to model, it is inherently open-ended. Inquiry learning proceeds blind to the outcome. It responds opportunistically to context and unanticipated factors. At each moment of inquiry, many divergent trajectories are possible (Figure 1). It is hard to predict in advance where the inquiry will lead. This is a challenge where an instutitional curriculum dictates fixed conceptual endpoints. How does one guide inquiry to the desired endpoint without eclipsing the opportunistic pathways that are so essential to the inquiry process? Namely, how can inquiry be open and close-ended at the same time?

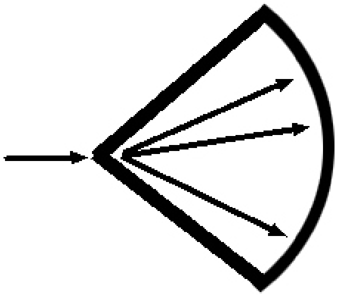

Figure 1. Divergence in inquiry.

Moreover, each successive step introduces new options, new opportunities, new possible trajectories (Figure 2). There are many problems to pose, many ways to frame any particular problem, many ways to design investigations, many ways to interpret results, many ways to imagine sequel investigations, and so on. One important lesson from history is that promising trajectories do not always yield expected discoveries, and unanticipated connections or contigencies sometimes lead to major breakthroughs (Burke, 1978). Which trajectory does one pursue, with what practical consequences? In an institutional setting, long-term planning and scheduling becomes exceedingly problematic. The

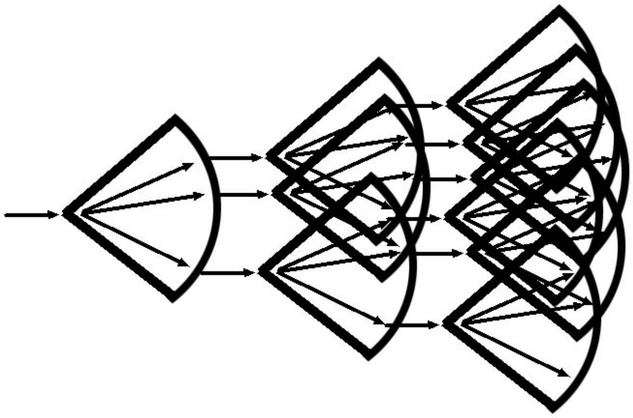

Figure 2. Potential compounded divergence in successive stages of inquiry.

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[1] I have presented this case widely, from high school and college biology students to secondary and university science teachers to science teacher educators, including groups in the U.S., Canada, Germany, Denmark, Norway, and Brazil. My comments reflect this experience.

instructor is in the same position as any investigator: facing an uncertain future, with the possibility that students will not resolve the problem at hand—an unsatisfying and educationally precarious situation.

In addition, by selecting one inquiry trajectory among many proposed in a group setting, one can easily alienate some individuals and foster counterproductive feelings of exclusion. Also, because learning proceeds through trial and error, error or "failure" seem inevitable. Feelings of discouragement may threaten engagement in learning or undermine an effective teacher-student relationship. All the politics and emotions can erode the student's investment in learning. In short, inquiry can be a very fragile learning structure, especially in group settings.

Historical knowledge provides the instructor with two potential solutions to these challenges for inquiry learning. The first benefits from historical awareness of the many possible trajectories in inquiry. A second draws on the situated perspective of a particular historical trajectory.

So: one possible way to solve the open-endedness of inquiry is to frame work within a relatively well defined "problem space." That is, being familiar with the history, an instructor can anticipate the potential scope of inquiry trajectories. With known boundaries, one can be relatively confident that students will encounter the relevant phenomena in a target domain and ultimately direct the inquiry to the institutionally prescribed conceptual understanding. That is, aware of the "territory," the teacher can gently and almost imperceptibly help students negotiate their way to a known endpoint. For example, William Harvey drew on a number of observations in deciphering the circulation of the blood. Because the solution is overdetermined, in a sense, by multiple lines of interconnected reasoning, students may reach a similar synthesis and solution through multiple inquiry pathways (Allchin, 1993).

As another example, consider learning about the basics of oxidation and reduction reactions by exploring the problem-space as understood in the 18th century (Allchin, 2013b, pp. 184–201). The relevant phenomena included combustion and calcination, reduction of ores to their metals, and photosynthesis (Figure 3). All these familiar reactions, involving both metals and organic materials, were related by the concept of phlogiston—which was added or removed or transferred in each

	Oxidation (phlogiston released)	**Reduction (phlogiston added)**
Metals	**calcination, rusting, tarnishing** ①	**reduction of ores** ②
Organics (carbon, wood)	**combustion** ③	**photosynthesis** ④

Figure 3. Historical problem-space for oxidation and reduction reactions, as interpreted through the concept of phlogiston.

process. In a classroom case, students explored this space on their own, alternating between simple lab activities and discussion — using charcoal to reduce copper sulfate to copper, burning candles and magnesium wire, and so on. The teaching team was positioned (knowing the historical problem-space) to nudge them on occasions into neighboring unexplored territory, sometimes with historical commentary. Thus, even though the students pursued the course of inquiry themselves, eventually they all encountered and interpreted the same relevant phenomena. The historical concept of phlogiston was introduced as a concept to help them unify their observations, and the actual history was discussed afterwards and compared with the students' own experience.

In this pedagogical approach, history primarily informed the organization of the prolem-space, allowing students to learn through inquiry. The real history was a supplement and an epilogue. But there were practical drawbacks. While four classes all covered the same material, they each pursued a separate sequence (see Figure 3):

Class A	4 --> 2 --> 5 --> 3 --> 1
Class B	2 --> 1 --> 3 --> 4
Class C	2 --> 3 --> 4 --> 1
Class D	1 --> 3 --> 2 --> 4

Preparing the lab for different investigative set-ups on the same day and monitoring and managing the divergent trajectories was exceptionally demanding on the teacher. Accordingly, in subsequent years, the teacher led all his classes along the same preplanned trajectory. The spontaneity and "ownership" of self-directed discovery, the essence of inquiry, was lost—illustrating again the practical problem of autonomous inquiry in school settings, even when informed by history.

An alternative inquiry strategy is to work in tandem with a professional scientist, purusing an authentic inquiry in the classroom (Crawford, 2012). Here, the scientist determines the trajectory. However, even though the science is unquestionably authentic, the students do not necessarily practice divergent thinking or rehearse the relevant skills. The students participate in but do not "own" the investigation. In addition, they implicitly learn that science is essentially about deferring to authority or specially privileged experts. Another option is for the instructor, or for the students themselves, to choose among the possible trajectories developed by different students within a class. But here there may be personal or interpersonal problems about whose idea gets selected. The classroom setting may thus be overrun with politics and emotions. And once again, a solution is not guaranteed. Ultimately, the whole inquiry experience may potentially feel empty, even if authentic.

Faced with such uncertainties, it is easy to imagine how an instructor seeking efficiency and control might turn to an idealized learning trajectory or a rationally reconstructed history. Such solutions promise a predictable teaching trajectory and guaranteed solutions. Ironically, however, such histories also tend to convey misleading lessons about the uncertain nature of science-in-the-making and typically upstage student engagement in divergent, open-ended thinking (Allchin, 2013b, pp. 77-92). "Cookbook" history as a prospective agenda for student inquiry will not help secure the intended lessons about how science works (any more than "cookbook" labs reflect genuine scientific investigation). For history to be helpful, one needs a different approach.

Historical Science-in-the-Making as a Guide for Inquiry

A historical narrative can help a teacher manage the challenge of diverging inquiry trajectories. Namely, the inquiry is first set in its original historical context. Science is still in-the-making. So the solution is uncertain. Student responses may freely diverge, even (at this point) from the actual history. Indeed, with historical awareness, the instructor may well anticipate how the students, echoing their historical counterparts, might variously think. They can encourage the development of alternatives within the historical horizon. After the inquiry work, students themselves may also possibly learn (and appreciate) how their thinking paralleled actual history. For example, consider the beriberi case, introduced above. Students typically raise questions or design experiments similar to those of Christian Eijkman, the scientist who is the central character of the story. They also usually find criticisms echoing Eijkman's own critics. Comparing student work with their historical counterparts is a form of validation—without having to characterize the work as either right or wrong. Students understand that they are doing "real" science, while still in a school setting. At the same time, the open-endedness of inquiry helps the teacher underscore the critical role of evidence and reasoning in context.

The central narrative then neatly provides the way ahead. Although many trajectories are possible, one proceeds by following the decisions or choices of the story's central character (Figure 4). It is partly an arbitrary choice. But it leads to a coherent and humanistic narrative. One can articulate the reasoning, without necessaily endorsing it. Historical events are not the benchmark for "correct" responses. The aim is not for the student to recapitulate history exactly. Nor is one committed to regarding the character's actions as always "right." Indeed, the students' own work may provide a context for viewing it skeptically. Later events will allow the assessment. In the beriberi case, one eventually discovers that Eijkman pursued a misleading theory—that beriberi was caused by a bacterial toxin, when ultimately it proved to be a nutrient deficiency. Still, Eijkman's trajectory provides a coherent way through the case, with corresponding lessons about the nature of science. The particularity, especially coupled with awareness of the alternatives, helps underscore that scientists inevitably practice within a personal conceptual perspective.

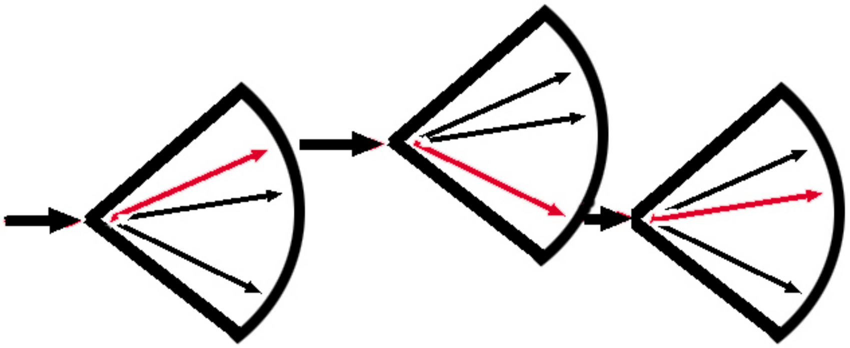

Figure 4. Successive divergences guided by an episodic historical narrative.

The central story then guides the students to the next occasion for inquiry (Figure 4). There, one entertains divergent thinking again. And, again, the narrative can "rescue" the teacher from the dilemma of which subsequent trajectory to choose. Because the history is authentic, not rationally reconstructed, students cannot always depend on the central character to reach the "right" answer. No "spoilers" upstage the actual drama of history, with its twists and turns, and unanticipated events. Because the trajectory is also somewhat arbitrary students are encouraged to understand that their own responses, when justified by evidence in context, were equally valid.

Eventually, however, the history converges on a solution. The actual events yield new findings that help resolve uncertainties or debate. So the teacher has a secure and predictable closure (see Henke & Höttecke [forthcoming] for teachers' concerns on learning the modern concepts). Even when the ending itself may be unexpected. The story of beriberi seems at first to be about disease and germ theory. But it ends with the concept of vitamins—ironically, a concept already familiar to most students, but not obviously relevant at the outset.

Historical cases, unlike contemporary cases (which may also illustrate the nature of science), have a known endpoint. One can eventually evaluate the process (Allchin, Andersen & Nielsen, 2014). Notably, this allows the instructor to situate a historical inquiry lesson with open-ended activities in a large-scale instructional plan.

The aim, here, is not for students to mirror history exactly. Indeed, the cognitive recapitulation model, positing that students develop in parallel to scientists through history, has been widely criticized and generally abandoned (Allchin, 2013b, pp. 86-88; Monk & Osborne, 1997, pp. 412-413; Swanson, 1995). Rather, history provides the occasions for inquiry, which is both contextualized and authentic. History frames a "lineage of questions," in contrast to an apparently foreordained series of discoveries (Farber, 2003; Mix, Farber & King, 1996).

History can thus provide a structure for guiding the course of inquiry or for mindfully sequencing a series of inquiry activities. The episodic structure maintains the uncertainty of science-in-the-making as it unfolds, allowing many opportunities for inquiry activities. The story functions as a fabric or structure to weave the inquiry together into a coherent whole. This differs from an expository or explanatory style of narrative. Here, the narrative serves the inquiry, rather than the inquiry or other activities serving to enhance the narrative. For example, when Metz et al. (2007) advocated "the use of imaginative and manipulative components within the narrative," they proposed that it "involves the reader in an ongoing interaction with the narrative" (p. 316). In the model of historical case studies profiled here, the inquiry learning instead is primary. The history takes a subsidiary role, functioning to involve the student in the inquiry and helping to shape an effective occasion for learning. The inquiry activity is not an adjunct to the history. The inquiry is the main lesson.

History & Motivating Inquiry

Given this general structure, there are several important features to the history that promote inquiry learning. The first — and arguably the most important — aspect of any teaching is motivating student engagement: the buy-in to active learning. Inquiry activities are no exception. The standard ideal is for students to select their own problems. But in practice, students may not have any "problems." Or their personal curiosity may not suffice to sustain a full investigation. In large classes, managing multiple individual projects is problematic. Alternatively, a joint consensus project does not generate uniform enthusiasm and commitment. The actual learning scenario in a school setting may be far less motivating than the theoretical model.

History can help. Indeed, teachers often turn to historical anecdotes or stories to help engage students in the content, absent inquiry (Henke & Höttecke, forthcoming). Here, however, history becomes a way to motivate *inquriy*. It provides an authentic problem and fully contextualizes it. First, cultural contexts help to justify the value of pursuing a particular problem, and thus science more generally (Stinner 1995; Stinner et al 2003). For example, in the beriberi case, one learns about the Dutch government's military and economic interests in preventing the disease. A historical narrative that focuses on one scientist also provides a more personal, biographical context, which helps to humanize the science. In the beriberi case, one learns about Eijkman's earlier background in Java, and how he became interested in medical research. Ironically, students need not have strong personal commitment to the problem at hand to appreciate its social and humanistic dimensions and to become invested in it for the sake of participating in a story. The teacher's first role in inquiry, then, is to render the historical context of the problem or unknown as culturally and personally compelling.

The nature of the motivation is specific here: to engage the student in a particular *inquiry* (see Henke & Höttecke [forthcoming] on teachers' concerns about staging historical cases). It is not merely to arouse the student's attention momentarily with a fascinating or amusing anecdote, before introducing the "real" lesson: the scientific content (Kubli, 1998; Metz et al., 2003, pp. 322–324). In this approach, history is not part of a "bait-and-switch" tactic. Nor is the underlying aim to promote a scientific career or change the image of scientists, another common use of history (Erten, Kiray & Şen-Gümüş, 2013; Hadzigeorgiou et al., 2012; Hong & Lin-Siegler, 2012; Seker & Welsh, 2003). The scientist need not be established as a hero at the outset, as the primary intent is not to establish or promote role models. Rather, the aim of the history here is to elicit the student's active investment in finding or learning about a solution. The orientation in the opening is specifically to motivate inquiry.

Historical Explanation & Learning through Narratives

Another virtue of history in inquiry is the narrative format itself. Stories are an integral part of human experience and a familiar form of sharing information. Indeed, our cognitive tendencies may be shaped by our evolutionary heritage as social organisms (Hsu, 2008). Stories certainly engage students. So narratives can be valuable vehicles for rendering any science lesson (Herreid, 2007), including scientific inquiry as a process (Norris et al., 2005).

But narratives are also typically more than entertaining descriptions. They are implicit explanations (Bruner, 1991; Carr, 2008; Norris et al., 2005, pp. 546–548, 557; Richards, 1992; White, 1987). They convey historical causation, by demonstration. Stories display "a logic of the flow of actions through time, a structure of events that gives them a distinctive form." A narrative "ties the action to its background circumstances, its antecedent events, and its subsequent results" (Carr, 2008, pp. 25, 29). For example, in the beriberi case, when students participate in the reasonableness of Eijkman's mistaken theory, and contrast it with later developments, they experience the roles of trial and error and conceptual change in science. The case renders the concept of "tentativeness," or potential for error, concretely in tangibly human terms, not generically or hypothetically

Indeed, humans may tend to think primarily in terms of exemplars and narratives, rather than abstract laws, even in science (Creager, Lunbeck & Wise, 2007; Kuhn, 1977). By situating inquiry processes in concrete scenarios, stories provide a cognitive framework that supports analogical thinking in other cases.

Ideally, then, the teacher will be well aware that historical narratives, like fables, have inherent "morals." They will reflect on the narrative content and use its explanatory power mindfully. For example, because stories have a potent affective component, one can easily instill an association of the intended lesson with the "wrong" reasons (Velleman, 2003). Similarly, stereotypes and melodramatic tropes that form the basis of so much familiar storytelling can misportray the nature of authentic inquiry or scientific practice (Allchin, 2013b, pp. 46-106). Effective use of the narrative format demands extraordinary care.

Yet narratives can also be powerful tools. They can depict concretely the relevance of a broad spectrum of factors that shape scientific work and its conclusions. Stories convey how they are all naturally integrated, although perhaps in different constellations in each case. Narratives are thus apt vehicles for rendering the nature of Whole Science, from its experimental and cognitive components to its human and cultural dimensions (Allchin, 2013, pp. 20-26, 39-40).

One consequence of the explanatory dimension of history, perhaps, is that any narrative structure, from among the diverse set familiar in literature or other contexts, should suffice for scaffolding a historical case study. There are many ways to tell a story, reflecting individual personalities and/or the demands of the occasion. There is no master narrative format or storytelling formula. Teachers may feel relatively free to craft an appropriate narrative, with certain provisos to be discussed below.

Inquiry & Historical Perspectives: Science-in-the-Making

Making the goal of student inquiry foremost does contextualize and thereby constrain the type of history that is appropriate. For example, where the aim is to motivate and frame student inquiry, historical perspective is essential (Allchin 2013, pp. 46-106; HIPST, 2008). One must foresake the convenient stories of "ready-made science," privileged by retrospect, and focus instead on "science-in-the-making" (Latour, 1987). One wants students to experience the science "in the shoes of famous biologists [or other scientists] and to face historically significant problems and original data, forsaking the privilege of already knowing the right answer." This perspective is fundamental "to faithfully portray how scientific knowledge develops" (Hagen, Allchin & Singer, 1996, p. vi). That is, the goal of inquiry-style learning is to understand how we research questions, grope towards solutions, and develop evidential confidence in justifying a solution, not how we rationalize an answer that is already known, by cherry-picking data and arguments that accord with it (Allchin, 2013b, pp. 84–86). A historical case should seem like a contemporary case merely displaced in time.

The principle of historical perspective, or of avoiding Whiggish history, includes a few basic proscriptions. One cannot divulge the ultimate answer prematurely. Nor can one provide any biasing clues. Either would upstage the intended inquiry effort and its fundamental uncertainty. So: there can be no foreshadowing. Likewise, there should be no obvious stacking of the deck towards certain outcomes or theories. Nor prejudicing character traits anachronistically based on later successes or failures. The phrasing of questions by a teacher that subtly anticipates a certain response will also subvert the goal of inquiry, just as it does when an activity is not embedded in history. Any such guidance to the students must be situated in the horizon of uncertainty as experienced by the student or their historical counterparts. No hints allowed. Ultimately, just as spoilers ruin the thrill of a good mystery, they also dissolve the essential motivation and rationale for inquiry. Thus, in the beriberi case, it is important not to pre-emptively announce, or even analyze, Eijkman's mistakes, or to conspicuously emphasize the need for a critical or skeptical attitude. Ironically, the lesson about the nature of error in science (also called "tentativeness") relies on quite the opposite: understanding how thoroughly reasonable all Eijkman's mistaken conclusions were, given the context and the available information. That requires respecting the historical perspective fully, with all its potential blind spots.

Also, for the sake of inquiry, a teacher must go beyond making the historical answers invisible. One must also suppress the role of history as an implicit benchmark or the historical scientist's work as a standard for assessing student performance. As noted earlier, the aim is not to recapitulate history. Rather, the role of history is to establish an open-ended scenario. Students must feel independent, uncertain, and responsible in pursuing their own inquiry. Elsewise, students can easily "opt out" and wait for the "real" (historical) answer. Or they can perceive the historical scientists as "geniuses," endowed with privileged insight beyond their own. They can continue to believe that scientific knowledge is preformed, delivered from authoritative sources; they will fail to appreciate how it is humanly constructed. They may also perceive the goal of science, like their own, as confirming pre-established truths (Henke & Höttecke, 2013). In borrowing from history to guide the framing of student inquiry, one must beware not to let it dictate its actual course or endpoint. The central NOS lessons rely on students experiencing blind science-in-the-making.

Notably, a historical inquiry, like any genuinely open inquiry, is "messy." The uncertainty is often accompanied by complexity and undetermination, and may provoke feelings of confusion, chaos, or insecurity (Allchin, 2013, pp. 121-132; Clough, this volume). These are additional emotional dimensions for teachers to manage (in themselves and students both). Oversimplifying the history, a common tendency among educators, runs the risk of destroying the essential historical perspective of science-in-the-making and erasing the very meaning of inquiry.

The historical perspective ought not be overstated, however. Students need not work exclusively within the conceptual constraints of history, especially if such concepts seem foreign or unreasonable (see Henke & Höttecke [forthcoming] describing teachers' concerns). Inquiry (embodying constructivist-style learning principles) requires students to think creatively and draw imaginatively on their existing repertoire of concepts. Students may surely be introduced to the historical theories or background, but need not be tutored in accepting them provisionally to govern their reasoning. Again, the goal is to foster inquiry, not repeat history exactly. Still, instructor awareness of historical theories, which sometimes resonate with students' uninformed views, may be helpful in managing students' personal reflections and group discussions. The role of historical theories can be made evident later, after the students' own inquiry activities, in reviewing the reasoning and actions of historical scientists. Historical theories need not — and probably should not — interfere with the process of the students' own inquiry.

Threading the Inquiry: Episodic Historical Narratives

The goal of inquiry, when set in a historical context, tends to invite an episodic structure (or *interrupted* narrative). That is, the story functions primarily in support of the successive inquiry activities, which form the core occasions for active learning. The narrative is alternately preamble and epilog, carefully crafted to frame the students' own thinking and then develop it further. For example, the narrative for the beriberi case is extensive. But it all revolves around contextualizing, informing, and interpreting the series of 14 inquiry questions, or "THINK" exercises, which form the primary source of learning. Some other effective examples of this format are McMillan's (2012) case on "The Snowflake Men," and Howe and Rudge's case on sickle cell anemia (Howe, 2010; Howe & Rudge, 2005; Rudge & Howe, 2009), Dolphin's (2009) multi-week curriculum on mountain-building (see also in this volume), and modules in the Minnesota Case Study Collection (Allchin, 2012).

The role of an episodic historical narrative, "interrupted" for inquiry activities, differs significantly from other approaches to interrupted stories. As practiced by professional storytellers, for example, interruption is a strategy to engage the listener, or foster "narrative appetite" and anticipation (Norris et al 2005, p. 541). Wandersee recommended just such a strategy for history in the science classroom: by "participating" in the story, students would increase their stake in following the outcome. Similarly, in role-playing historical scientists, he would ask his audience questions or seek their opinions on his actions (Eleanor & Wandersee 1995; Roach & Wandersee, 1993, 1995; Wandersee, 1990). While interruption can be a powerful storytelling technique, its role in inquiry cases is quite different. The emphasis is on the students' own thinking, not making the story more important. Ideally, it should foster an "appetite for inquiry," not merely a "narrative appetite" for more of the story. The students should become more interested in trying to determine the outcome themselves, or participating in creative problem-solving, than hearing the story recited to them.

In a sense, then, it is the inquiry that is interrupted, not the narrative. The history contributes a sense of continuity across the successive occasions for divergent thinking. The inquiry is punctuated. The epilog of one episode segues seamlessly to the preamble of the next. The history can thus condense large spans of time, making it possible to address large-scale inquiry projects in a classroom setting.

Teachers generally find the interrupted format congenial to classroom practice (Reid-Smith, 2013). Most notably, it balances opportunities for autonomous student activity with instructor control of overall instructional flow. It also changes the rhythm of a class period frequently, promoting sustained student attention. Perhaps for these reasons, interrupted cases are the most popular among users of the National Center for Case Study Teaching in Science (Herreid,, 2005; Herreid et al., 2011; 2012, p. 73; although the cases are generally not historical).

The significance of an interrupted, episodic structure for inquiry has an interesting consequence for how one use historical cases in the classroom. Namely, teachers find it awkward relying too heavily on students passively reading a narrative text, especially during class time (Henke & Höttecke, forthcoming; Reid-Smith, 2013; Rudge & Howe, 2009, p. 565). A focus on inquiry seems to resonate instead with the teacher as narrator or presenter, perhaps using images that help visualize the problem, the scientists or their work.

Inquiry about the Nature of Science

The inquiry approach to history thus tends to shape strongly how history is used. But the role of history, in turn, can also dramatically shape the nature of inquiry lessons. In particular, a great virtue of history of science is in highlighting the nature of science, or scientific practices, or how science works. Accordingly, the focus of inquiry may shift. Inquiry questions that might, on other occasions, be directed solely to understanding scientific concepts or to simple scientific practices found in a classroom, now include nature-of-science, or NOS, questions. This is *NOS inquiry*, not just scientific inquiry. Historical narratives open the way to *problematizing* NOS (Allchin, 2012, 2013b; Clough, 2006; Howe, 2007). One asks, thematically, "how do we know this?" and "how do we investigate this?" Not merely, "what is the evidence?" or "How does one justify this particular claim?", but "what is the nature of good evidence?" and "what, in general, constitutes adequate justification?" Well chosen historical examples can highlight problematic situations, and thereby introduce epistemic questions: namely, those about how scientific knowledge is developed and comes to be accepted as trustworthy.

Ideally, then, NOS lessons are not taught directly through the instructor's observations or comments any more than scientific concepts. Rather, students actively investigate NOS, through problem-posing, analysis, reflection, and discussion—*about the nature of science or scientific practices*. For example, in the beriberi case, students are asked standard science inquiry questions about planning investigative variables, interpreting experimental results, developing alternative theories, and designing experiments to compare two different explanations. But they are also invited to reflect on deeper NOS problems: on the burden of proof in scientific versus social policy contexts, on the nature of human subjects in experiments, on the nature of bestowing credit in science, and on the nature of error. Again, the historical narrative helps contextualize and *motivate* the inquiry, now about NOS. The answers are not explicitly provided. Instead, the students must grapple with the issues and find resolution in discussion, possibly informed by understanding the later outcome of the episode. Ideally, they should come to understand that scientific practice is structured precisely to respond to certain needs: for trustworthy conclusions, unambiguous communications among scientists, reliable instruments, rigor balanced against the limits of available funding and time, and so forth.

Generally, NOS questions may (at first) be raised by the teachers, not by the students themselves. Still, students should be able to readily comprehend and appreciate their relevance and significance. All case-based or problem-based education is structured to some extent, and even an inquiry-based instructional plan will foster autonomy or independence in only some dimensions (Allchin, 2013a, pp. 369-370). Here, the NOS questions may initially be provided for students. Still, they serve as explicit models or exemplars for students to follow. Namely, they illustrate important questions that students may ultimately learn to ask themselves, notably in contemporary cases of socioscientific issues. In this way, history may contribute to developing *NOS analytical skills,* where students not only understand NOS, but have learned to delve into NOS for themselves (Allchin, 2013, pp. x).

NOS inquiry is not necessarily isolated. It can be integrated with more conventional inquiry on scientific concepts, rendering a holistic sense of scientific practice, or Whole Science (Allchin 2013, pp. 20-26, 39-40; Hagen, Allchin & Singer, 1996, pp. v-vii, 198). This coupling has been recommended especially in current institutional climates and teaching cultures, where conceptual content remains the dominant focus (Clough, 2006; Heilbron, 2002; Henke & Höttecke, forthcoming; Monk & Osborne, 1997; Rudge & Howe, 2009).

Resolving Inquiry and the Historical Narrative

Perhaps the greatest conundrum for any student-led inquiry is reaching closure. How does one shepherd the open-ended process to a known endpoint—say, the modern scientific concept typcially at the core of a conventional lesson? The teacher who guides the students too strongly or conspicuously towards the "correct" or desired endpoint risks destroying the core epistemic lesson: that there is no external, omniscient authority to guarantee "the truth." A teacher cannot maintain the integrity of inquiry while also rescuing students from a crisis of uncertainty or the possible chaos of an unwieldy investigation. Any authority who resolves a troubled inquiry *deus ex machina* ultimately subverts the core NOS lessons.

The narrative informed by history is critical in achieving convergence. First, one consults history in part because one knows that there is indeed a solution before embarking on a path of "open" inquiry. Teachers can pose the original question or problem secure that there *is* some scientific closure now. (In this way, a historical case differs importantly from controversial contemporary cases.) Second, the history documents the investigations, evidence and reasoning that helped settle debates and led past scientists to select among alternative conceptual interpretations. Criticisms are answered. Exceptions are clarified. Qualified judgments wane. Debate subsides. Confidence in a stable solution emerges. Moreover, the relevant experimental results or evidence may well be beyond the reach of a school classroom — perhaps based on expensive instrumentation or prolonged time scale of study or professional levels of expertise (whether about fossil identification or seismic data or statistical models). History can conveniently collapse time, substitute for material human efforts, and catapult over pecuniary hurdles of funding research. Students are able to participate vicariously in an inquiry that would not be possible for them otherwise. Third, the narrative format allows the instructor to lead the students through these encounters in an authentic way. The history gradually comes to the "rescue," but clearly not by any clairvoyant agency, superhuman insight, or supernatural teleology. Indeed, the history is liable to reveal all the unanticipated contingencies that led to key results. Once one recounts how events unfolded, the students are ready to participate in engaging them and reaching final conclusions themselves.

Because narrative and inquiry are coupled, the denouement of the narrative parallels the resoluton of the central problem that originally motivated the inquiry and lauuched the historical story. Closure is thus achieved in two ways at once. The scientific problem is solved. At the same time, the narrative journey reaches its anticipated destination, with attendant emotions. In this double closure, the explanation for how science works, implicit in the history, becomes complete. The finished story *explains* science as a process. The narrative brings the science and the nature of science together, with an emotional knot for the student with a personal stake in the inquiry.

Ironically, closure can occur even when the ending may be wholly unexpected. When Dave Keeling began, he was trying to ascertain whether the concentration of carbon dioxide in the atmosphere was uniform globally. His story ends, however, several decades later, after he had produced monumental evidence for anthropogenic global warming (Leaf, 2012). Originally, Carlton Gajdusek wanted to trace the cause of the disease kuru in New Guinea. Ultimately, he ended up discovering an entirely new kind of disease transmission, identified even later as a prion (Gros, 2011). The ultimate ending in science, like many captivating stories, may be unanticipated at the outset.

The process of closure is especially important for understanding scientific practices or the nature of science. A completed narrative allows one to pair the remembered experience of science-in-the-making, with its perspective of uncertainty, with the retrospective view of completed science, after the interpretations of the evidence have stabilized and the justifications seem established. This comparison helps students appreciate how what appears in the textbook as "ready-made science" was ultimately "constructed" historically—via contingency *and* evidence, through chance *and* necessity. The complexity of the process (embodied in the story) coupled with the objective structure of the evidence and logic of the justification (understood through inquiry discussions) seems essential to understanding the relationship of process and product in science.

Finally, the closing offers an occasion for comparing student performance with the actual events from history. The history is not the authoritative benchmark. But it is still a valuable point of reference in retrospect. Students can see the variety of possible pathways forward. They can note the difference between the actual history and a perhaps idealized version of it, exhibiting the tension between descriptive and normative conceptions of science (Allchin, 2013, pp. 107-120). The roles of politics, personal perspectives, cultural values, or other contextual elements shaping science become clearer.

Consolidating Inquiry Learning

The final stage to any inquiry, or constructivist learning episode, is the consolidation of the lessons. Here is where one guides the students in drawing and appreciating the "morals" of the story. One cannot expect stories to "speak for themselves" as evidence for the nature of science any more than the scientific data "speak for themselves" in forming theoretical conclusions in science. As Tao (2003) noted,

> When studying the science stories, many students selectively attend to certain aspects of the stories that appear to confirm their inadequate views; they are unaware of the overall theme of the stories as intended by the instruction. (p. 168)

Indeed, science teachers can take an entire history of science course and fail to learn much about the nature of science (Abd-El-Khalick and Lederman, 2000). Thus, the closure of the lesson, which accompanies the closure of the narrative, involves explicit reflection on those NOS lessons (Clough, 2006; Craven, 2002; Howe, 2007; Klopfer, 1969; Kurdziel & Libarkin, 2002; Peters & Kitsantas, 2010; Russell, 1981; Scharmann, Smith, James, & Jensen, 2005; Seker & Welsh, 2005; Yacoubian & BouJaoude, 2010).

In closing a historical inquiry case, the teacher (with student participation) explicitly recalls or identifies the various historical factors that led to the outcome. But ultimately, the students must complete the reflection on their own. In the beriberi case, students are invited to reflect—and ideally formalize their thinking in writing—about many features of the nature of science: the cultural context of science; the role of theoretical preconceptions; the role of chance, or accident; the nature of controlled experiments; error and conceptual change; and so on. This ensures cognitive integration of the NOS lessons, made possible by the closure of the inquiry and the closure of narrative and the simultaneous completion of the historical explanation.

Summary

The model using episodic historical narratiaves as a guide to inquiry thus has several elements of structure, all supporting the aim of inquiry learning:

- a motivational context from history, both cultural and biographical, for asking questions or posing problems and for investigating them;
- a narrative format that supports a historical explanation of the process of science, through a case example;
- historical perspectives that render the uncertainty of science in the making, so essential to open-ended inquiry;
- an episodic, or interrupted, narrative that pauses for divergent inquiry thinking at particular moments in history, informed by and connected by a historical thread;
- questions that problematize the nature of science and promote nature-of-science inquiry, in addition to scientific inquiry;
- closure of both the scientific inquiry and the historical narrative; and
- a final occasion for explicit reflection and consolidation of lessons.

These elements, collectively, embody or support the conventional principles of inquiry learning, and help explain why historical narratives can be so effective for learning science and the nature of science.

At the same time, the structural elements do not constitute a narrow algorithm for how to write a narrative or historical inquiry case. There is no one “narrative method”—any more than that there is one exclusive scientific method. There are as many possible narratives as there are narrators, perhaps. The structural features that I have outlined focus, instead, on the foundational principles of inquiry learning and NOS instructional goals that help make sense of why one might turn to history to enrich science and nature of science education.

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