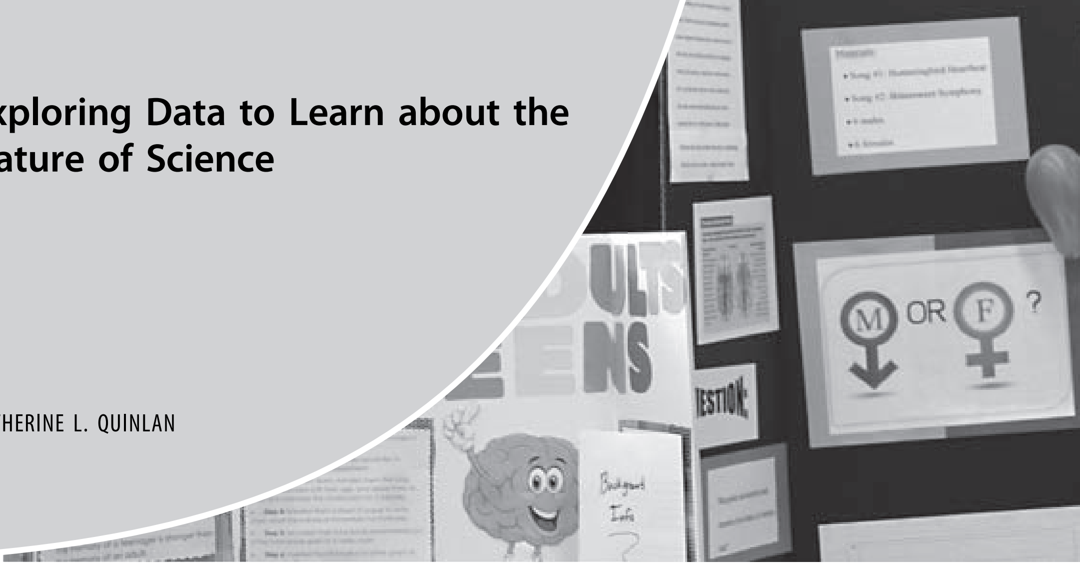
Exploring Data to Learn about the Nature of Science



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Abstract

Biology is often taught as disconnected facts, even though the subject itself provides a holistic approach to the study of life, particularly through the overarching frame of evolution. The Framework for K–12 Science Education and Next Generation Science Standards *promote a coherent approach to science that uses a developmental approach to learning. This is consistent with the use of data, reflective strategies, and a research inquiry approach that encourages students to confront their own thinking and reasoning, and thus encourages the engagement of argumentation in the classroom. This article presents narratives and classroom scenarios that might provide insights into learning strategies, with implications for a more cohesive approach to learning both biology concepts and the practices of science.*

Key Words: *Data; evolution; nature of science; biology; research projects; journals; inquiry; literacy.*

○ Introduction

One of the ambitious goals of the *Framework for K–12 Science Education* produced by the National Research Council (NRC) is coherence within science education. To achieve this goal, the *Next Generation Science Standards* (NGSS) espouse a more holistic approach to learning science that not only considers the importance of literacy and math skills to success in science, but also encourages us to approach "learning as a developmental progression . . . allow more time for teachers and students to explore each idea in greater depth . . . [and integrate] the knowledge of scientific explanations . . . and the practices needed to engage in scientific inquiry" (NRC, 2012, pp. 10–11). In many ways, the adoption of NGSS might address the challenges posed by the understated uniqueness of biology as a science.

Classroom scenarios describe how students engage with evolution data through reading reflections and discussions.

In his book *What Makes Biology Unique?*, Ernst Mayr indicates that the uniqueness of biology lies in its holistic nature, very unlike the more reductionist science of chemistry or physics. Yet many topics in biology require an understanding of the physical sciences, and it is unfortunate that ninth-grade biology classes often come before an adequate understanding of relevant chemistry concepts. Some perceive biology as a subject only requiring memorization of terms and think that biology is the easiest science, at least in high school. However, the reality is different in college: at the undergraduate level, biology suffers from high attrition, with an average dropout rate of ~50% (Astin & Astin, 1993, p. 1165; cited in Feldon et al., 2010).

In order to consider biology learning as a developmental progression, learning within biology needs to be inextricably linked to learning within the individual. Dewey (1933, p. 236) notes that "learning, in its proper sense, is not learning things, but the meanings of things, and this process involves the use of signs or language in its generic sense." Moreover, this process takes time to accomplish, and more time to explore ideas might mean less content covered. Here, I address ways to approach the learning of biology as a developmental progression through the *use of data*, *reflective reading*, and a *research* or "*journals experiment*" approach. Classroom scenarios describe how students engage with evolution data through reading reflections and discussions, and how they create their own data in a long-term project. Resources and possible extensions to the activities are also provided. The descriptive examples have implications for fulfilling a more cohesive approach to learning biology and the nature of science, as encouraged by the NRC *Framework*.

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○ Using Data in the Classroom

Data derived from experiments or surveys can be available in many forms – as facts, figures, numbers, images, sounds, statistics, and more. When students use data to make calculations and draw conclusions, they may seek patterns or infer cause-and-effect relationships that support or refute a research question, claim, or working hypothesis. Overall, students can make large gains in their learning of concepts and in their meaningful understanding of what they have learned when complex data are used and when they confront many issues through the use of data (Gerber & Reineke, 2005; Kanter & Schreck, 2006).

○ Reflective Reading of Evolution Data

Geology professor Karl Wirth believes that it is important to help students learn how to learn and supports a developmental approach to student learning (Wirth & Perkins, 2008) in his geology classes and in teacher workshops on metacognition and learning. Wirth believes that students learn better "through better reading and reflecting" (Wirth & Aziz, 2015, p. 1). In a collaborative and controlled study between Macalester College and Hamline University, Wirth and Aziz (2015, p. 2) found that "in courses with reading reflections, students report more regular . . . and deeper reading before coming to class . . . [and] report using a greater number of strategies during the pre-reading, reading, and post-reading" phases – and receive higher grades overall. This would mean that students develop strategies as they perform meaningful and active reading reflections. The professors also reported that they themselves became more metacognitive about their own teaching. Ertmer and Newby (1996) believe that reflection on the learning process provides the link between knowing and controlling the learning process. Therefore, it is possible that reflective reading could lead to reflective learning and, ultimately, to more awareness and control of one's learning.

A reflective reading approach was used to guide student learning of Darwin and evolution. Data from a past exhibit on Darwin at the American Museum of Natural History were used (see Table 1 for other data sources). That exhibit included excerpts from Darwin's manuscripts and notes, details of his travels, questions he pondered, information on his personal life, details of his discoveries, and journals of his discoveries from various places – information that is usually not provided in a textbook. Students received a handout on reading reflection (see Table 1) and responded to three questions prior to each class: (1) What is the main point? (2) What is surprising? (3) What is confusing? The narratives and interpretations below provide some insights into classroom conversations and possible classroom scenarios.

○ Narrative on Reflective Reading: Bringing Darwin Home

Students, some of whom were not previously vocal in class, expressed the elements of their surprise or confusion. They were surprised that people initially thought that Earth was only 6000 years old instead of 4.5 billion years old, and that few naturalists "were even asking such questions." This led to discussions on the roles and perspectives of various naturalists, issues that were important to that time, how people lived back then, people's concept of time, their relationship to and view of the environment, the effects of the industrial evolution, and the role of science and technology, some of which were described in the exhibits.

Students connected with Darwin not only through his work but also on a personal level. They were surprised that Darwin was bored by school but were fascinated by his passion for other things, especially those things that went against the desires of his father, such as shooting and collecting beetles. The readings placed the young life of Darwin in the context of his time, when people were fascinated by geology and when discussions about the history and age of Earth were ongoing – discussions that shed light on Darwin's resulting ideas about how species formed. Students learned that Darwin not only grew up privileged but also had a difficult childhood, with a sick mother who died when he was eight years old. Despite this, Darwin became known as the student who constantly asked questions, pursued chemistry experiments at home, collected beetles, took a botany course three times because he liked botany, and whose desire was different from his father's dreams for him. Students were confused, however, about why someone like Darwin kept his "revolutionary idea" to himself for a long time and why he "shunned the public eye," which led to speculations about the nature of Darwin as a scientist in his time.

Students reflected on the practices of science that eventually led Darwin to construct his theories. They were amazed by the number of notebooks Darwin filled with careful observations and that the trip on the *Beagle*, initially planned for two years, took five years instead. Students reflected on excerpts of Darwin's writings and his questioning of his own observations, which led him to observe patterns, to defer his questions to expert scientists at home, and to link the geology of the land with fossils discovered, even as he was seasick and missing his family. His speculations, doubts, reliance on others, and challenges, as he attempted to balance personal and professional life, were visible through comments such as "I knew no more about the plants I had collected than the Man in the Moon." Thus, the readings humanized the nature of Darwin and his scientific and thinking processes, bringing it home to students, even as they learned specifically about species, adaptations, and unique penguins that lived at the equator. Moreover, the student-driven discussions provided insights into students' views and reasoning, and enabled interesting discussions led by students' questions – thus providing a context for discussion of other scientific perspectives on evolution not addressed by the exhibit or found in their textbook.

○ "Journals Experiment"

The method of data collection used by Darwin – in which he not only collected specimens but spent a great deal of time writing his observations, questions, and thoughts that were important to him – is very similar to NASA's 2010 "Journals Experiment" on human physiology and adaptation, focused on human performance during expeditions to the Antarctic and the International Space Station (ISS). While the South Indian Ocean mission consisted of nine researchers and the ISS study consisted of 10 subjects, not enough for statistical significance, NASA thought that it was reasonable to assume that if someone repeatedly wrote about a subject it was

Table 1. Resources and ideas for using data.

Data/Lesson Resource	Questions, Concepts, Data Addressed
Gateway to Astronaut Photography of Earth: Crew Earth Observations This site provide images of places taken by scientists as they navigate Earth on the International Space Station http://eol.jsc.nasa.gov/AboutCEO/	From an environmental science perspective, students can use the data to tell a story using scientific concepts. Moreover, this is a great way to create a multicultural connection (i.e., students can choose information about the places from which they came or they can request pictures of NASA scientists and hence make a connection with these scientists). Questions might include • What is the nature of the biome here? • Which other places have a similar biome; why? • What can I learn about life in this particular place? • How is this place analogous to another place? • How can specific biology concepts be used to explain this place? What new information or images do I need to find to answer my research question? • What can I learn about Earth or life by viewing these images?
Darwin Manuscripts Project: http://www.amnh.org/our-research/darwin-manuscripts-project Past Exhibitions: Darwin: http://www.amnh.org/exhibitions/past-exhibitions/darwin	Extension to Darwin's journey around the world. Imagine that you were Charles Darwin and that you decided to explore the world to gather evidence. What kinds of questions might you ask? What observations might you make? What inferences might you make? Students can use the images to generate observations, inferences, claims, and questions, and to create a journal or digital portfolio for the data they gather. Darwin Online: http://darwin-online.org.uk/ Darwin Correspondence Project: http://www.darwinproject.ac.uk/
"Mars – The Xtreme-o-philes" Mars Education at Arizona State University http://marsed.asu.edu/content/xtreme-o-philes	Students "conduct an investigation and construct explanations for the validity of extremophiles in specific Mars environments" (http://marsed.asu.edu). Extremophiles are organisms that live in extreme environments, such as extreme heat, acidity, alkalinity, and salt. The lessons and activities use real scientific data from extreme environments on Earth that provide analogues for regions on Mars. The activities align with both NGSS and CCSS for high school and middle school (Biological Evolution: Unity and Diversity, Ecosystems: Interactions, Energy, and Dynamics, Independent Relationships in Ecosystems), as indicated on the website.
Reading reflection handout http://www.macalester.edu/academics/geology/wirth/readingreflection.pdf	This handout (derived from a teacher workshop by Professor Wirth) can guide various biology content. Students can reflect on scientists' biographies and respond to video clips or specific science readings. For example, students can write reflections on excerpts from the video *The Making of The Fittest* (http://www.hhmi.org/biointeractive/making-fittest) to encourage discussion and reveal students' prior conceptions or misunderstandings of biology concepts as they attempt to explain evolution concepts.

important, and that months of continuous journal writing provided a large enough amount of data for analysis. The goal of this experiment was to evaluate the effects of isolation and confinement on long space missions, to quantify the human factors in the journals, and to use the information to inform future expeditions (Stuster, 2010). The journaling by Darwin and by these scientists has implications for the nature of science. Not all scientists perform experiments; for example, theoretical physicists do not (Wong & Hodson, 2008). Moreover, not all scientists who perform experiments carry them out in a lab setting.

Similarly, biology students used journals in a seven-month project that was divided into a research phase, an experimental phase, and a presentation phase. The use of journals over a long period provided a holistic approach to studying biology, as students worked progressively at their own pace to answer reflective questions and do scaffolding activities, such as creating concept maps to make sense of articles or evidence, making connections between biology concepts and applications, or writing outlines for their research paper. Students engaged in practices that the NRC describes as "crosscutting concepts" – concepts that transcend content boundaries and in which performance depends on the knowledge and ability of the student. For example, students used pattern recognition to ask questions. They investigated cause-and-effect relationships and used various crosscutting concepts to create explanations.

The success and the nature of their projects led me to ask students if I could write about their work. Interested students and their parents signed consent forms and returned their journals to me at the end of the school year. Student success was indicated not only by feedback from other teachers but also by some students' continuing interest in working with me on similar projects. For example, student interest led me to apply for a competitive high school research program offered by NASA's Lunar Planetary Institute, which gave students the opportunity to work with a scientist. Furthermore, during the year in which students did not do a long-term research project, due to time constraints, testing concerns, and lack of support, there was less interest in future work that involved extensive research. The narrative I describe next is not the results of a study, but a report on students' experiences supported by the goals of the NGSS. These reports have implications for providing experiences that allow students to approach learning in biology holistically, considering not only cognitive outcomes but also outcomes in the affective domain of learning.

○ Narrative on Long-Term Project: Students Create Data

Students chose a range of topics based on their curiosity and personal interests – such as music, video games, cancer, malaria, plants, race, Alzheimer's disease, and so on – an initiative encouraged by the NRC *Framework*. One student who chose music noted that "This topic is special since I listen to music right after I get out of school and [don't] stop until I go to sleep. I know that your hearing gets worse but listening to music gives an advantage to your brain." Students engaged in various scientific practices while performing their investigations. They asked questions such as

- Why do some people become dependent on drugs while others that are exposed to the same environment do not?
- How do genetics play a role in the likelihood of someone becoming addicted to a drug?
- Why do we have different skin colors?
- Why are there only black people in some countries?
- Why do people get so addicted to smoking after knowing that it is bad for your body?
- Does gender impact the power of a person's memory?

They "derived meaning from scientific texts (such as papers, the internet . . .)" (NRC, 2012, p. 53). They revised their research questions, claims, or hypotheses to make them testable. They used creativity to gather data, as many of their topics did not lend themselves to lab experiments. Some worked collaboratively and enthusiastically to conduct survey questions and interviewed the school community, even if they had slightly different research questions. Others performed experiments more consistent with qualitative research. For example, two students with the same topic teamed up to ask, "How different is the life of someone with Alzheimer's than that of a person without the disease?" Their goal: "To get a first-hand experience of an Alzheimer's victim's daily life and the people around them. I will be able to complete this hypothesis by watching videos on the lives of Alzheimer's patients and their families." They took notes on video clips they found on YouTube and other websites where families describe their experiences with Alzheimer's. They sought for patterns and tabulated and diagrammed the results. Another student, who claimed that "Music affects the way your brain functions by giving an individual better memory," proceeded to give students words to remember with and without music. Finally, students analyzed, graphed, tabulated, and wrote explanations for their data in lab reports and then communicated their findings to the school community using posterboard presentations (Figure 1). The principal and some teachers expressed amazement at the nature of the research done, the depth at which students went into their topic, and their ease in explaining; a few presenters were English-language learners and students with learning difficulties.

For the teacher in a content-rich biology class, this was a tremendous undertaking, which included balancing the task of covering the biology curriculum while accomplishing this long-term project. It also provided opportunities for discussions and to link students' topics with biology concepts – for example, cancer with the concept of cells and cell division, and music or video games with the brain and the types and roles of cells.

When students embark on such long-term biology projects, there are many opportunities to discuss the nature of science with them. For example, it is important to proceed with caution when students are creating their own data instead of using secondary or available data. Harris et al. (2012) noted that during students' explorations, they tested for conductivity in water as an indication of the amount of salt in the water; they ended up with insufficient evidence from which they drew generalizations when using their own data (primary data). So they compared their primary data with secondary data, which Harris et al. (2012) defined as data collected by scientists, often over a long period of time. The advantage in using secondary data is that "Long-term data sets allow us to see both slow trends and rare but sudden ones, and help us see patterns where there is a lot of variability" (Harris et al., 2012, p. 481). Therefore, the more long-term a project, the greater the implications for research that more resembles scientific pursuits, as scientists can spend their entire careers pursuing one research question.

As noted in the NGSS, "learning about the nature of science requires more than engaging in activities and conducting investigations" (NGSS Lead States, 2013: Appendix H). Learning about the nature of science takes time and commitment to the process. Students displayed elements in the affective domain that went beyond Krathwohl et al.'s (1964) first individual level of commitment to learning, which is described as "a willingness to receive information; directly related to motivation" (cited in Wirth & Perkins, 2008, p. 7). Some were "responding [or] showing some new thinking or behavior as a result of an experience, [others were] valuing [or] finding worth or value in a subject, activity, assignment" (Krathworth et al., 1964; cited in Wirth & Perkins, 2008, p. 7),

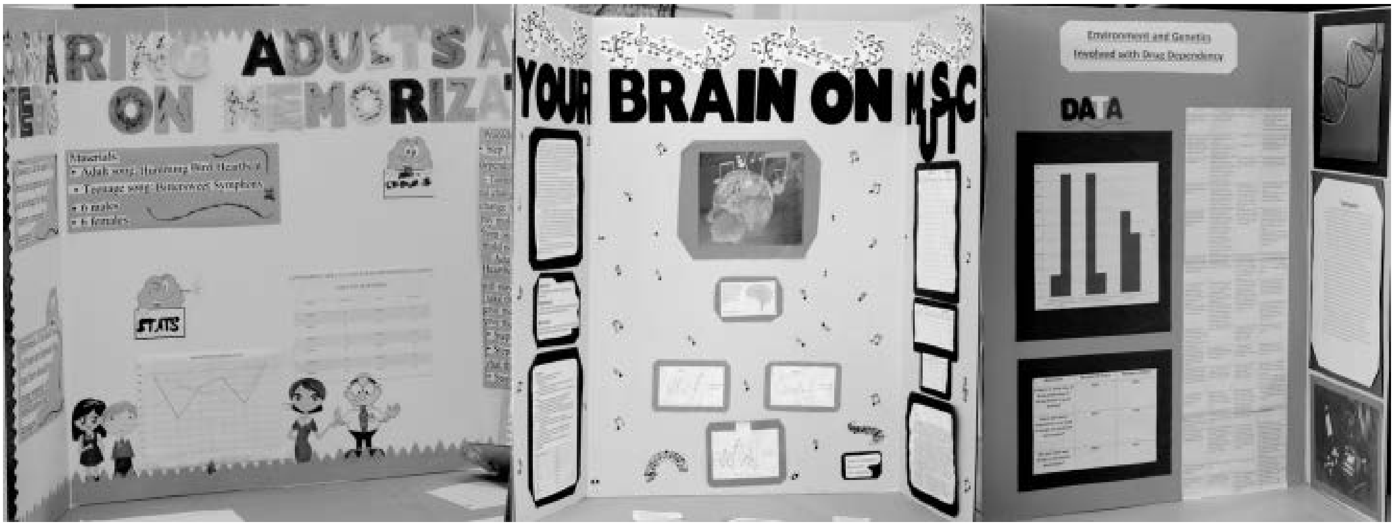

Figure 1. Students' poster presentations.

and still others were "organizing [or] integrating new information and values into one's set of values" (Krathworth et al., 1964; cited in Wirth & Perkins, 2008, p. 7). It is possible that some might have achieved the highest level of commitment to learning in this affective domain, which is "acting based on a value set [or] acting consistently with the new value(s)" (Wirth & Perkins, 2008, p. 7). This highest level would be more consistent with what some describe as procedural knowledge (Anderson, 2005), planning knowledge (Marshall, 1995), or having reorganized their preexisting knowledge structures to accommodate the new incoming information that resulted in a modification of their preexisting knowledge structures (Bartlett, 1932; Piaget & Inhelder, 1969). Research would have to be done to determine this.

○ Advantages & Disadvantages

There are advantages and disadvantages to the methods of using data described here. The reflective questions ask students to express what is surprising or confusing. This encourages students to express their thoughts, as they feel more at ease when not expected to simply convey correct answers. These reflections, therefore, reveal the reasoning processes and encourage prolonged discussion to ponder specific ideas. They promote implementation of argumentation, which is defined as "critique and evaluation" (NRC, 2012, p. 44), a process encouraged by the NGSS. The use of a "journals experiment" or research journals provides a focus on process and not simply outcomes of research. Thus, it provides opportunities to make students' reasoning or inconsistencies more visible, to help them draw conclusions from observations or data, or to relate information to other science concepts. These methods not only humanize the sciences and the scientists but also help students engage in various practices of science through language communicated in writings and discussions. However, for the teacher of a regular biology class, it is an enormous undertaking that takes a great deal of classroom and individual time. For the professor who needs to balance teaching and research, it is time consuming. Therefore, support systems would need to be in place to enhance success for any educator. This could be in the form of reduced class loads, reduced number of students, and/or reduced biology content. Consideration must be given to the uniqueness of biology as an applied science, which, in and of itself, provides a holistic approach to understanding nature, for example by taking into account the foundations of biology. Table 1 provides some additional ideas and resources.

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