First-Year Students Benefit From Reading Primary Research Articles

By Laura Wenk and Loel Tronsky

Primary research articles discuss aspects of scientific inquiry that are important in understanding the nature of science. Yet, most introductory science courses use textbooks that ignore the scientific process; opportunities for explicit discussion of the nature of science are lost. In Hampshire College's science program, students read current primary research articles throughout their college careers. This article describes the pedagogy used and demonstrates that first-year students can make considerable progress in critically evaluating the research literature. A sample of 41 students in introductory natural science courses made statistically significant improvements in their abilities to explain the experimental design, data collection methods, and results sections of primary research articles over the course of their first semester. As Hampshire is a small liberal arts college, this article includes ideas for incorporating primary literature into many types of college science courses, large and small.

Most science faculty have goals for their students related to understanding the nature of science. They hope their students will learn to generate ideas, test them, make decisions based on evidence, and evaluate claims and counter claims (American Association for the Advancement of Science 1989; National Science Foundation 1996; National Science Teachers Association 1987). These outcomes entail complex scientific inquiry skills and understandings that can be difficult to teach and are often nearly absent in science textbooks (Abd-El-Khalick, Waters, and Le 2008). Primary research articles illuminate aspects of scientific inquiry that textbooks ignore, discussing the research question, the authors' hypotheses, the experimental design, and the results. Many research articles illustrate the "spiral" nature of scientific research, discussing the origin of the research question, alternative explanations for the data, and ideas for further research that could help distinguish among competing claims (Muench 2000; Yarden, Brill, and Falk 2001). Engaging students in critical evaluation of primary articles can be a powerful pedagogical strategy to teach thinking skills related to the scientific research endeavor. The articles, when chosen well, also add to the subject matter objectives of the course.

There are many fine examples of programs that successfully engage upper-level science majors with the primary literature (e.g., Herman 1999; Houde 2000; Janick-Buckner 1997;

Klemm 2001; Roberts 2009). At Hampshire College, we believe that early experiences reading primary literature affect how students approach scientific problem solving over their college careers. We often hear doubts that students can reason about experimental design and data interpretation concerns if they lack the requisite science knowledge. In this article we present evidence that first-year college students can learn to read primary literature and that doing so improves their understanding of the scientific process. We discuss how it is used at Hampshire College and ways to adapt its use in varied teaching contexts.

In the first-year introductory science program at Hampshire College, students choose focused, topical courses according to their interests (e.g., Human Biology taught in a case-based approach; a physiology course, How People Move; and a geology course, Geological Controversies). Within these courses, students are taught explicit strategies for critically reading primary literature. For example, when students are given their first research article, many faculty support students with the handout in Figure 1, "Tips for Reading Primary Literature." Then, students typically go through several cycles of reading primary articles and providing individual and/or group responses to structured questions. Assignment structure and use of class time allow for explicit discussions about the role of prior research and theory in developing a research question and hypothesis. Students are taught to evaluate research designs and results, and they develop evidence-based explanations of scientific phenomena.

As the culminating experience of most 100-level courses, each student focuses on a course-related topic, forms a question, and finds evidence in the primary literature to answer that question. Students report their findings in a paper that is subject to critique and revision. The faculty use primary literature in the general coursework in order to scaffold the development of the skills needed for students to succeed in their independent research. Though Hampshire College's first-year courses are not typical, many of the individual assignments can be used in larger, more traditional courses or in upper-level seminars (see Figure 2 for a list of ideas).

When primary literature is used in college, faculty often select historically pivotal research articles (Levine 2001), edit articles to make them more accessible (Levine 2001; Smith 2000), or assign the abstracts alone (Rettig and Smith 2009). But controversy in science is not just a

FIGURE 1

Tips for Reading Primary Literature handout.

Even though the vocabulary and format may feel intimidating at first, you'll soon get used to both as you learn more about the subject and read more papers on related topics. Also, you'll have more questions—some about content or technique and others about how the work was done.

Most primary articles begin with an **abstract,** which summarizes the major points of the study (what was asked, what was done, what was learned). If the subject is new to you, the abstract may be hard to understand because it doesn't explain much. It sometimes helps to scan an abstract to see if the research is even close to what you want to know.

The **introduction** is usually helpful because it sets out the rationale for this study by telling you four things:

- the general topic the paper addresses,
- previous work that led to the question asked in this study (citations to studies included in the bibliography are given, but few details of that work are mentioned),
- the question(s) the study you are reading is designed to address, and
- the authors' hypothesis(es).

The first time you read the paper, you might want to skip from the introduction to the discussion to get a quick idea about what they conclude.

The **methods** section often has lots of technical details, so at first, focus on two things:

- An overall picture of the experimental design. Sometimes this information is set out more clearly in the introduction or the abstract, but it's important for you to step back from the details and figure out why they designed the study as they did (more about this in the handout on experimental design).
- Details about each step of the experiment (some of these—like how they chose their subjects and how many subjects they studied and over what period of time—will be important to understand right away; others have more detail than you need to worry about).

The **results** section shows the results of tests described in the methods section. It shouldn't have much in the way of conclusions. What it will have are tables, graphs, or diagrams. The text of the results discusses some of what is in those figures, but you'll need to look closely at the tables and graphs to really understand the results.

The next section is generally called **discussion** or **conclusions.** That's where the authors remind you of the original question(s) they were asking and address how well they think their data answered those questions. They may refer to other studies that help explain some of what they found or expected to find and didn't. They may speculate in this section about what their results might mean (including any alternative explanations) and what further studies they believe need to be done and why.

The final section is the **bibliography.** This is very useful as you're getting into a new topic. It tells you who else is working in the field and what work was done earlier that led to this study.

thing of the past, so the Hampshire College first-year science program requires students to find and read current literature that is not edited by their instructor. The faculty have been using primary literature with students for 30 years, originally following the model set by Epstein (1972) whereby first-year courses are run in the style of graduate seminars, interrogating the literature by pursuing student-generated questions. Natural science (NS) faculty have further adapted the pedagogy (Bruno and Jarvis 2001; D'Avanzo and McNeal 1997; McNeal 1989) and have teamed with cognitive science researchers to describe student learning outcomes. We developed a research instrument that was integrated into their courses as a way to assess primary literature skills. We observed classes and interviewed faculty to find out how they taught students to better interpret a research article. All findings, in addition to being reported here, were presented to the NS faculty.

In this article, we use one course, Drugs in the Nervous System, as an exemplar of using primary literature to teach the mode of scientific inquiry. (*Note:* This course is no longer offered, as the instructor has recently retired. Nonetheless, the pedagogy is typical of that used in many introductory NS courses at Hampshire.) Figure 3 shows how the coursework is structured to support students by using both collaborative and individual activities. Here we describe our research findings on the effects of these and similar pedagogical strategies on students' ability to tackle authentic scientific literature in their first semester at college. This research adds an outcomes-oriented dimension to the discussion of the use of primary literature in college classrooms, as much prior research has used informal impressions of student gains (Levine 2001; Muench 2000) and/or has used less direct indicators of student development, such as student attitudes and satisfaction (Houde 2000; Janick-Buckner 1997; Smith 2000).

FIGURE 2

Ideas for using primary literature in the introductory science classroom.

Write about a graph or table: Before assigning an entire article, give students one important figure from the paper. Ask them to write a few paragraphs describing what they think the study is about and what the researchers found.

Question, methods, data, and conclusions (QMDC): Students write about the question, methods, data, and conclusions of an entire journal article or for one figure in a paper.

Find variation: Select a figure from your textbook that is adapted from a figure in a research article. Copy the original figure for your students. Have them describe the differences between the two figures. Chances are, all or most indications of variability in the data have been removed for the textbook. Discuss what this means for their understanding of how scientific knowledge is created.

Augment the text: Assign one or more journal articles that give a "peek behind the scenes" on textbook topics. Ask students to discuss (in writing or aloud) what the literature adds to their understanding of the topic and/or the process of science.

Update the text: Students update a textbook topic using at least one primary source; all students write up their findings for the same topic, or this assignment rotates with different pairs giving brief in-class presentations when their textbook topic comes up.

Update the review: Students read an older review article on a course topic, then find, read, and write a report that updates one idea covered in the article.

Applications: Students find, read, and report on a current applied issue related to a less applied lecture topic.

Historical research: Students find older primary articles that show the early development of a theory covered in class.

Lab report literature review: Students write a literature review section in their lab reports. This might be particularly effective in labs that span more than one week in order to give students more than the usual one-week, report-writing deadline. In order to more closely replicate authentic research, consider creating labs that require students to pool data sets across lab sections, design the experiment themselves, and/or answer a novel question (one to which you do not know the answer).

Highlight controversy: Assign two articles that lead to different conclusions—perhaps assigning a different article to each half of the class. Use presentations or debate to help students understand the reasons for disagreement. Use this to highlight different types of studies (e.g., cellular mechanism versus clinical studies) and ways scientists interpret findings.

In all cases, you will have greater success if you are explicit about your goals, give students feedback on their performance, and make the activity a meaningful part of the course. Teach students how to read the literature. Give written assignments, require oral presentations, or include exam questions that check for student understanding (questions could include content as well as issues of experimental design and data collection, how to weigh evidence, reasons scientists disagree, etc.). Assessment must be aligned with your goals.

Methods

This research was implemented in inquiry-based, first-year courses that serve both science majors and nonmajors at Hampshire College. A sample course, Drugs in the Nervous System, serves as an exemplar. In this course, Julien's book *A Primer of Drug Action* (2001) was used for background on how nerves work and the actions of specific psychoactive drugs, and also as a reference source. The bulk of the readings were primary articles, including a packet of teacher-assigned primary articles and a series of articles students found using library databases, specifically pertaining to their own final projects. The course activities were geared not only toward understanding the content, but also toward making sense of the literature. The structure of the course and the nature of the assignments are described in Figure 3.

Students were given novel primary research articles to read at the start and end of the semester as a regular class assignment. The instructor chose the pre–post articles to be comparable (in terms of length, complexity, etc.), while also coinciding with the topics and concepts covered during class at that point and allowing for discussion of research issues (e.g., explaining the origin of the research question in prior research, having reasonable alternative explanations, etc.). Students wrote responses to the set of questions in Table 1 for each article. The essay questions were designed to tap students' understanding of eight important conceptual units in a scientific article. Students brought two copies of their pre–post article essays to class—one to be used to fulfill the course requirements, the other to be used for research purposes.

We explained the purpose of the research to students and secured informed consent for the use of their work in this study. Participation was voluntary. Students benefited from the research in that faculty were taught how to use a rubric to give students specific feedback on their work (see Figure 4). Of the 46 students from the intact first-semester courses, there were 41 matched pairs of pre–post responses.

The pretest primary article and assignment were administered during the first week of classes; the posttest

FIGURE 3

Structure of a sample first-year course using primary literature.

First primary article assignment: The parts of a research article

Day 2: Students assigned primary article (Olson 1997). Students asked to bring list of confusing vocabulary to class.

Day 3: Instructor defined and explained terms.

Day 4: Students reread paper for understanding and assigned guiding questions (see Table 1). In class, eight small groups each collectively answer one assigned question. Groups create posters and present. Students are encouraged to jot notes on their papers, showing what they learned from presentations. After handing in the amended assignment, students received feedback on their understanding of various facets of the article (see Figure 4).

Second primary article assignment: Applying what they learned

Students studied text (Julien 2001) for content. Then they read a research article concerning that content, using the same eight questions (see Table 1), again receiving feedback with rubric (see Figure 4).

Third primary article assignment: A focus on experimental design

Small groups of students were given different articles all on the same topic. Each group prepared a structured summary focusing on the methods and results, especially selection of control groups. Using a "jigsaw" framework, groups gathered by article to get facts clear, then regrouped across articles, explaining their paper to others. Finally, each jigsawed group answered a specific question such as: "Which study had the best control? Explain." "What were the different criteria used to choose participants and how did those criteria affect the outcomes?" "What is your conclusion about the initial research question?" Before presentations, instructor checked proposed answers for accuracy and depth.

Fourth primary article assignment: Generating questions and finding appropriate literature

Students were asked to find articles using library databases. Science librarian taught them her approach to searching (Selin 1989). Small groups generated questions and found articles relevant to assigned topic. Ten-minute class presentations afforded the opportunity to discuss use of research.

Capstone experience: Finding and using research articles

Each student applied course learning in independent investigations, structured as follows:

1. Identify a broad idea within the scope of the course (e.g., antidepressants).
2. Generate a more specific topic (e.g., sexual side-effects of Prozac).
3. Find appropriate research literature (hand in annotated bibliography).
4. Present a specific hypothesis (e.g., "Prozac causes problems with sexual functioning in a substantial number of patients").
5. Summarize one article you found using the guiding questions (see Table 1); include specific analysis of a table or graph.
6. Get feedback through peer editing before turning it in.
7. Repeat for a second article.
8. Hand in a draft paper.
9. Revise according to feedback from instructor.
10. Give a final oral report, summarizing one research article in the context of the research question, and presenting the data from one table or graph.

We recognize that not all college science courses would support such extensive project work as a way to get students involved in reading primary articles. Figure 2 contains a list of shorter activities that engage students with the literature. These are activities that we have used at Hampshire College or learned from others.

TABLE 1

Primary research article assignment—student essay questions.

1. What question is addressed by this research? Explain the relevant past research and the ideas that led to this question.
2. What hypothesis was investigated in this study? Explain how it is related to the research question you discussed in #1 above.
3. How was the study set up? Explain why it was set up this way.
4. What data were collected? Explain why the authors chose these particular data to collect.
5. What were the results?
6. Explain how well the results do (or do not) support the hypothesis.
7. Explain any alternative explanations for the findings (your own ideas and/or the author's).
8. What further research does this study suggest (to you and/or the author)? Explain why it should be conducted.

was given after nine weeks of instruction that included intensive focus on critical reading, as outlined previously and described in detail in Figure 3. Ideally, half the students would have been assigned the articles in the current order and half in the reverse order, in order to control for any variations among the papers. This was not possible as the articles were so well integrated into the instruction.

Student responses were coded by question for each student. There were three levels at which a response for any given question could be coded "misunderstands concept," "mentions concept," or "explains concept." The three levels represent the degree to which students engaged with important science concepts. Although the concepts students wrote about are field specific, they map onto higher-order epistemological ideas. For example, one way to merit an "explains concept" score for the hypothesis question (#2 in Table 1) is to "explain how theory or mechanism leads to hypothesis." Implicit in this score is an understanding that scientists look for causal mechanisms and/or test ideas that are related to current theory. Students were not expected to explain this epistemological stance in their essays. Instead, we coded for whether students mentioned or explained how the proposed mechanism, prior research, or theory, etc., was linked to the specific hypothesis for the research at hand. The paper-scoring method was developed in a pilot study. In both the pilot study and the results described herein, two independent coders scored the responses; both were blind as to students' names and whether the articles were given pre- or postinstruction.

There were different possible reasons that student responses were coded at any one of the three levels, and so subcategories were developed. For example, in question 2 described previously, discussing how prior theory leads to the hypothesis is one subcategory, describing how prior research findings lead to the hypothesis is a second subcategory, and discussing what is known of a mechanism for the phenomenon is a third subcategory. The two coders gave matching level codes for 73% of student responses, with virtually all disagreements being between adjacent levels. Coders gave matching subcategory codes on 59% of responses. There was no evidence that one coder systematically gave higher or lower scores than the other. Coders resolved all disagreements through discussion.

The total number of codes was calculated for each question at each level for each participant. The first analysis was conducted by collapsing across

FIGURE 4

Primary literature feedback rubric.

Question	**Strong answers** Articulate and explain the conceptual issues raised by the question by elaborating on medium answers	**Medium answers** Articulate the conceptual issues raised by the question	**Weaker answers** Miss important conceptual issues raised by the question and/or are confused about the science involved
Question and importance—Context of the study			
Hypothesis			
Methods (setup)			
Data collected			
Results			
How well results support hypothesis			
Alternative explanations			
Further research			
Additional comments:			

questions and making pre–post comparisons within the three coding levels to see how response levels changed in general over the semester. Next, a comparison was made for each question at each coding level using paired *t*-tests to document changes in responses to individual questions.

Results

Table 2 shows examples of the different levels of students' answers to the same article, demonstrating what we considered a misunderstanding, mention, or explanation of a concept for the question on data collection. Clearly, there is a wide range of sophistication among these 41 students. The pre-, post-, and difference means for numbers of codes per question by coding level are summarized in Table 3. Values were multiplied by 100 to remove decimals.

Analyzing pre–post changes across the questions, we found a significant increase in number of "explains" responses, a nonsignificant decrease in "mentions" responses, and a significant decrease in "misunderstands" responses (see bottom of Table 3). Separating the analyses by question, we found significant differences from the pre- to postassignment for the responses to the hypothesis, setup, data collection, and results questions. In all cases, the direction of change was toward better student performance.

TABLE 2

Sample student responses and codes assigned to those responses.

Question	Sample responses	Code assigned and explanation
What data were collected? Explain why the authors chose these particular data to collect.	The data collected were the Battelle Developmental Inventory (BDI) and Home Observation for Measurement of the Environment (HOME) scores. They chose these tests because they would show not only cognitive development, but also the way in which the environment was affecting them. The BDI tests various levels, thus it gives results in many areas of development. It was also used because it was standardized on 800 children from a wide spectrum of socioeconomic backgrounds, has high correlation coefficients for test–retest reliability, and acceptable content validity. Test developers of the BDI intended it to be used to identify children at risk for developmental handicaps, meaning this test was targeting exactly what the study wanted to see. (Hurt et al. 2001, paper #3106)	**Explains—provides an explanation of data, discussing design considerations.** In this response, the student goes beyond reporting simply what data were collected. This student articulates what the different tests are measuring, why these tests are the correct tests to use (sound psychometric properties such as reliability, validity, and standardization and they measure multiple facets of development), and also notes the importance of the environmental measure to compare its effect versus the effect of cocaine exposure.
	At 6 to 30 months, children were tested under the Bayley Scales of Infant Development. At 30 months, the Preschool Language Scale was used. At four years, the Wechsler Preschool and Primary Scale of Intelligence-Revised provided intelligence quotients. At three and five years, the BI was used for evaluation of the subjects. It is broken up in five categories: Personal-Social, Adaptive, Motor, Communication, and Cognitive. At four years, the home environment was assessed using the HOME test. (Hurt et al. 2001, paper #3004)	**Mentions—tells data without mentioning design considerations.** In this response, the student mentions all of the important data that were collected. There is no explanation of the significance of using these particular measures.
	At the three-year test, the control children weighed more than the cocaine-exposed children, and at the five-year test, the control group was slightly younger. Also, at both intervals, fewer of the cocaine-exposed kids were in the care of their biological mothers. Both the cocaine-exposed and nonexposed children scored similarly on the Bayley Scales of Infant Development, the Preschool Language Scale, and the Wechsler Preschool and Primary Scale of Intelligence–Revised. (Hurt et al. 2001, paper # 3037)	**Misunderstands—confuses with results.** This response calls into question whether the student understands the distinction between the data that were collected and the analyses performed on those data.
	Growth percentile was collected. The children's caregiver also had an interview so that the researcher could see what kind of environment the child was raised in. Home observations were given. (Hurt et al. 2001, paper #3158)	**Misunderstands—misses detail.** This response does not reflect that this student understands the data that were collected to evaluate the researchers' hypotheses. The student neglected to mention much of the important data (e.g., the BDI measure).

No significant pre–post changes were found for responses to the question/importance, alternative explanation, and future research questions.

Discussion

The evidence above indicates that students (science majors and nonmajors alike) can make significant gains in understanding primary literature in one semester when exercises to promote understanding are conducted on a regular basis. Our research shows that this can be started very early in the curriculum for all students.

Entering students were more adept at understanding the research question and its importance than at understanding questions of research design and data analysis. They did much more explanation in their presemester essays on the research question than on other items and made no significant improvement on this question. One interpretation of this result is that students came to college understanding that scientific experiments are designed to answer research questions with specific purposes in mind. As such, they were careful to attend to the purpose of the research. Another interpretation is that in the genre of scientific writing, the introduction to the primary research article is often more accessible than the data-driven portions of the work, so the article scaffolded students on this question. In either case, there was less room for improvement and no statistically significant change in their responses at any level to that question.

TABLE 3

Pre–post scores on primary literature assignment by question and level of response.

Question	Level of answer	Prescore	Postscore	Pre–post difference
Research question/ importance	Explanatory	24	29	5
	Mentions	107	117	10
	Misconception	22	20	−2
Hypothesis	Explanatory	7	10	2
	Mentions	76	115	39*
	Misconception	34	12	−22*
Setup (design)	Explanatory	5	24	20*
	Mentions	120	85	−34*
	Misconception	15	12	−2
Data collected	Explanatory	7	27	20*
	Mentions	78	66	−12
	Misconception	29	10	−20*
Results supporting hypothesis	Explanatory	0	29	29**
	Mentions	105	56	−49**
	Misconception	56	34	−22
Alternative explanations	Explanatory	5	10	5
	Mentions	39	41	2
	Misconception	76	54	−22
Future research suggestions	Explanatory	2	5	2
	Mentions	59	51	−7
	Misconception	61	61	0
Totals	Explanatory	7	19	12*
	Mentions	83	76	−7
	Misconception	42	29	−13*

Note: Prescore, postscore, and pre–post difference scores are the average number of checks received per person multiplied by 100; this transformation was done to remove decimals to facilitate scanning and interpreting the table. Some difference scores were affected by rounding.
*Significant change, $p < .05$ **Significant change, $p < .01$

The significant improvement seen in questions 2, 3, and 5 (hypothesis, design, and results, respectively) in “mentions concepts” and in “explains concepts” for questions 3, 4, and 5 (experimental design, data collection, and results, respectively) are very likely an indicator of improved ability to understand the article itself. This increase is coupled with a consistent, though generally not statistically significant, decrease in misunderstandings for all questions. Students were better able to pick out important points, if not elaborate on them, for the data-driven portion of the articles. These changes are in keeping with the pedagogy used in the course. Students were given ample opportunities to analyze the results, explain them, and analyze them in relation to the design of the experiment itself. These findings indicate success in an important first-year course goal at Hampshire College—helping students understand the process of science.

The analyses also show that some aspects of primary literature may require more extensive and perhaps more structured exercises. For example, students’ ability to propose alternative explanations and future research was very poor initially and did not improve much over the course of the semester. One possible explanation for this is that students may need to first develop a better understanding of the investigation itself (which, on average, students did) before they can start reflecting on the study to pose alternative explanations for the data and related future research. Another explanation is that recognizing and posing alternative explanations requires a sophisticated epistemology of science, one in which students understand the interpretive nature of scientific knowledge claims. Changes in thinking about the role of interpretation of data in building scientific knowledge are unlikely to occur in one semester (Wenk and Smith 2004). Skill-building activities related to alternative explanations or future research may be more suitable for later in the semester, and real change likely requires continued work in subsequent courses.

Although we have demonstrated that students can critically evaluate primary literature, further research on the specific activities that promote specific skills is needed. For example, would more explicit instruction on the theory-bound nature of data interpretation lead to greater sophistication in students' responses to alternative explanations? In addition, we have not looked closely enough at students' library research process. One important question is whether improved abilities to interpret primary literature lead to a greater likelihood that students will seek out primary articles from varied sources and address controversy among sources in their research papers. This is a potentially fruitful area of research—one that we intend to address in future studies. ■

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