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Incorporating Primary Scientific Literature in Middle and High School Education †

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Primary literature is the most reliable and direct source of scientific information, but most middle school and high school science is taught using secondary and tertiary sources. One reason for this is that primary science articles can be difficult to access and interpret for young students and for their teachers, who may lack exposure to this type of writing. The *Journal of Emerging Investigators* (*JEI*) was created to fill this gap and provide primary research articles that can be accessed and read by students and their teachers. *JEI* is a non-profit, online, open-access, peer-reviewed science journal dedicated to mentoring and publishing the scientific research of middle and high school students. *JEI* articles provide reliable scientific information that is written by students and therefore at a level that their peers can understand. For student-authors who publish in *JEI*, the review process and the interaction with scientists provide invaluable insight into the scientific process. Moreover, the resulting repository of free, student-written articles allows teachers to incorporate age-appropriate primary literature into the middle and high school science classroom. *JEI* articles can be used for teaching specific scientific content or for teaching the process of the scientific method itself. The critical thinking skills that students learn by engaging with the primary literature will be invaluable for the development of a scientifically-literate public.

INTRODUCTION

Students receive the majority of their scientific information and news from secondary and tertiary sources. In the science classroom, students typically learn from textbooks and sometimes popular science articles. Outside the classroom, students increasingly receive their science news from social media outlets such as Twitter, Facebook, and Reddit (10, 12). These crowdsourced platforms provide little to no objective, scientific review of the legitimacy of their content but instead prioritize information based on the "aggregated opinion of others" (11). In these settings, reports on scientific findings are often sensationalized because of the need to increase page views to generate advertising revenue. As the amount of information available on the Internet increases exponentially, so does the amount of biased and ill-informed reports, which are often difficult to differentiate from legitimate scientific sources. Not only do these misleading reports generate false beliefs, but they also misrepresent how scientific research is performed and evaluated (3, 6, 13). Students cannot be prevented from using these social media sources, and it would be just as difficult to convince those who share science-related information in these forums to critically evaluate the credibility of the information.

One solution to this growing problem is to teach students to use the Internet to access and learn directly from the primary scientific literature, rather than from secondary or tertiary sources. This approach removes the layers of other people's (mis)interpretation from students' access to scientific information. Peer-reviewed primary literature provides evaluated scientific content, and reading the primary literature consequently strengthens student understanding of the scientific process (5, 8, 16). Moreover, engaging with primary scientific literature teaches students how to rigorously evaluate information from others and how to accurately communicate scientific information to others. Developing these skills in all students will be an important first step in creating a scientifically literate citizenry that is capable of critically evaluating any type of information.

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Connecting students to scientists

How then can we teach students to engage with, and learn from, primary scientific literature? Incorporating primary literature in the classroom can prove daunting, in part due to many articles' narrow focus, their use of jargon, and sometimes their physical inaccessibility (14). Additionally, we cannot solely rely on schoolteachers to impart this education, since classroom time is often already stretched too thin and scientific communication and the research process can be unfamiliar subjects for teachers. One approach is to turn to scientists themselves to give students a better understanding of how the former perform hypothesis-driven research and effectively communicate their findings through peer-reviewed journal articles. To achieve this goal of promoting scientific literacy by connecting students with scientists, we formed the open-access, peer-reviewed *Journal of Emerging Investigators* (*JEI*, www.emerginginvestigators.org). *JEI* is a free, online, non-profit science journal dedicated to engaging middle and high school students with primary scientific literature by having scientists mentor and evaluate students' research for publication. *JEI* benefits students and teachers in two ways: 1) the peer-review and publication processes are educational experiences for the student-authors and their mentors, and 2) the resulting repository of student-written scientific articles serves as an age-appropriate, Internet-accessible tool for teaching any student how to read and interpret primary literature. As a completely free and online journal, *JEI* offers an alternative to Facebook or Twitter as a source for readily-accessible scientific information that is written by students, for students. At the same time, *JEI* maintains the structure and integrity of academic peer-reviewed science writing.

Scientific review as an educational experience

JEI was started in 2012 and is still maintained by researchers at Harvard Medical School. The structure of the journal and its publication process are modeled on a typical academic journal, with three editors-in-chief who manage the publication process, a team of over 40 editors, who are each responsible for overseeing the publication of between one and four manuscripts per year, and over 75 expert scientific reviewers, many of whom are Ph.D. candidates or research fellows at the various research schools at Harvard University. The publication process is outlined in Figure 1 and is very similar to that of other academic journals. The first step in the process is for students to submit their research manuscript using the *JEI* website (www.emerginginvestigators.org), which also provides extensive guidelines for writing and submitting articles. Upon submission, the manuscript moves to the second step, in which the editor assigns three reviewers with expertise in the subject(s) of the article. The third, and critical, step is the peer-review, in which the scientists critique the manuscript and provide feedback on how to improve the research methodology, interpretation, and communication. In this way, student-authors are connected to scientists and gain valuable feedback on how to improve their scientific research and/or communication of their work. We believe that this peer-review process is the most important part of the educational experience for students, indeed as it is for professional scientists themselves.

Since one of the main missions of *JEI* is to teach the scientific process through primary literature, it is imperative that each *JEI* article portrays the scientific method clearly. Therefore, *JEI*'s peer-review process places high value on how well the research question, hypothesis, and experimental approach are articulated. For example, each article is required to have a well-defined rationale that builds on previous scientific evidence. In addition, each article needs to describe clear experimental setups and controls, although we recognize that it may not be feasible

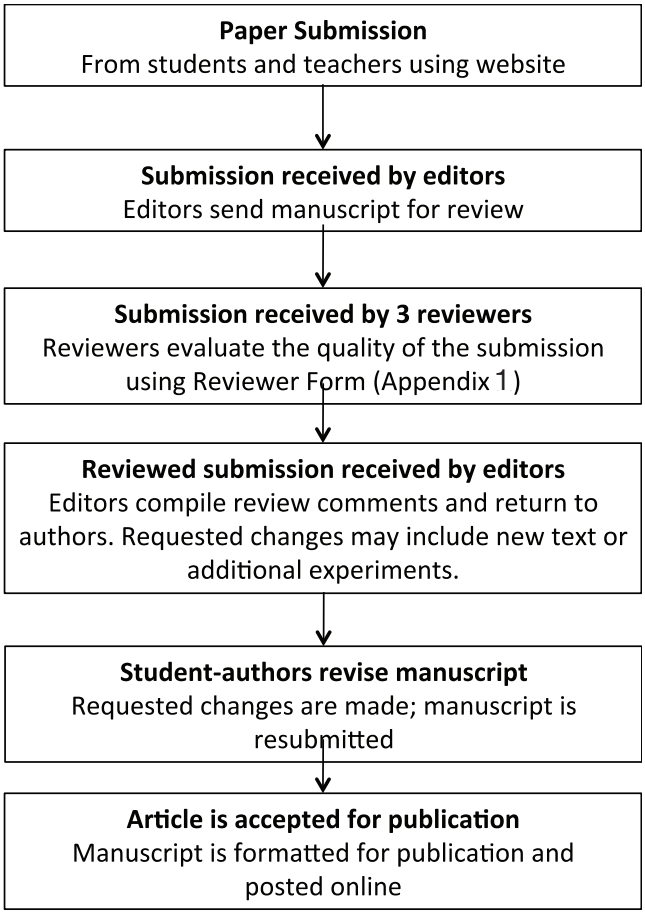

FIGURE 1. Outline of the *JEI* publication process. Students, along with their mentors (teacher, parent, or scientist), submit their original research manuscript through the *JEI* website. Editors select three scientists with expertise in the subject of the study to review the manuscript for scientific and written clarity. A manuscript will always require some changes or modifications prior to publication, and these changes may be minor communication changes or larger changes that require additional experimentation. Accepted papers are copy-edited and published on a rolling-basis on *JEI*'s website. There are no costs associated with *JEI*.

for some student-authors to perform all ideal controls. Student-scientists must also ensure that their experiments are safe, ethical, and comply with the International Rules for Pre-College Science Research (17), provided on *JEI*'s website. Finally, *JEI* asks students to write discussions that demonstrate deep thought about the implications of their work, even if the experimental parameters were not perfect and the results inconclusive. Different from other academic journals, *JEI* is aware that this review process is a learning experience for the student, and so reviewers are also instructed to provide encouraging remarks to the students to embolden them in their pursuit of science. In particular, reviewers are reminded that the manuscript was composed by young students and thus to adjust their expectations accordingly. *JEI* manuscripts do not have to examine a novel scientific question that has never been tested previously. Instead, *JEI* simply asks that student-authors propose scientific questions to which they themselves do not know the answer. *JEI* also acknowledges that students will have access to varying types of scientific equipment, and requires reviewers to evaluate the manuscript based on the quality of the scientific method and not the sophistication of the techniques. Overall, we have found that even the most unlikely submissions can be improved to publication quality, and only in dire cases such as breaches of scientific integrity would a manuscript be rejected. In these ways, *JEI* transforms peer-review into an age-appropriate educational experience wherein student-authors and their teachers are mentored by scientists throughout the publication process. For a more in depth description of how *JEI* manuscripts are reviewed, see Appendix 1, which contains the full reviewer evaluation form.

Journal articles as educational tools

We realize that performing original research and writing a scientific manuscript for submission to *JEI* is not feasible for many middle and high school students and teachers. In order to benefit all students, and not just the select few student-authors, *JEI* also provides a free, online repository of age-appropriate primary science articles that can serve as an educational resource for all students and their teachers. To facilitate *JEI*'s mission to incorporate primary journal articles in everyday science education, *JEI* employs a team of outreach volunteers who provide hands-on instruction at science fairs and festivals, middle and high school science classes, and extracurricular science clubs. We also design and teach workshops for middle and high school science teachers and science department chairs for continuing professional development credits. One teacher-participant of a *JEI*-organized professional development course commented that *JEI* "took a topic that seemed out of reach and made it doable." Another participant stated that *JEI*'s introduction to primary literature "gives me new ideas on how to include writing in science." In *JEI*'s outreach efforts, we demonstrate that the opportunities to use journal articles in the science classroom are vast. *JEI* articles can be used to teach students about specific scientific concepts contained within the articles, as well as the scientific method and science writing itself. Teachers can benefit from using *JEI* articles as background reading when the subject pertains to the lesson at hand. For example, there are several *JEI* articles that investigate some aspect of climate change that have been successfully used to supplement climate education in the high school classroom (2, 4, 7). *JEI* articles are also useful for teaching broader concepts such as the scientific method and the peer-review and publication processes. For example, one article entitled "The effect of music on heart rate" is scientifically simple enough for middle school students to understand, but still provides an excellent example of developing a hypothesis, designing experiments and discussing implications of the work and limitations of data interpretation (1). We have had great success using this specific article to engage the public at science fairs, to teach high-school students how to critically evaluate a research study, and to educate teachers about the structure of a scientific article. For many more specific ideas about how to incorporate primary articles into the science classroom, a selection of recommended lesson plans is summarized in Table 1, and one of our most popular and easily-adaptable

TABLE 1.
Ways for students to use primary science articles in the classroom.

READING	• Search online for primary articles on a topic of interest as part of a research project
	• Read an article as a background reading assignment instead of a textbook
	• Compare and contrast a research article with a news article on the same subject
	• Journal club A: entire class reads an article and critically evaluates it together
	• Journal club B: each student presents a different part of the article to the class
WRITING	• Write a journal article manuscript instead of a lab report for a preexisting class laboratory
	• Write an abstract to an article provided without its abstract
	• Write a "Results" section that fits a provided piece of data (e.g., a table of results)
	• Peer-review an article by listing each section's strengths, weaknesses, and needed next steps
	• Peer-review other students' lab reports and/or manuscripts
	• Design a follow-up question and experiment for an article (then e-mail ideas to study's author!)

Part of *JEI*'s mission is to encourage the incorporation of primary literature into the middle and high school classroom. Here, we provide a selection of lessons that we and others have used successfully to engage students with *JEI* articles and other primary literature. Many of these can be done in groups, and/or as part of an active learning module.

activities is described in detail in our accompanying article published in this themed issue (9).

Current outcomes and future directions

Since *JEI* began in 2012, we have published over 50 articles written by student-scientists that cover a range of scientific fields, all of which are available for free download on the *JEI* website (Fig. 2A). Student submissions come from all over the US and abroad (Fig. 2B). While the majority of the articles are written by high school students, there are several articles that have been written by middle school scientists and one article written by elementary school scientists (15). In addition, *JEI*'s research content is diverse, from psychology to physics, and only continues to grow as *JEI* increases its publication rate (Fig. 2C). This variety in the reading level and scientific content in *JEI* articles makes it easy for teachers to find and use articles in a diversity of contexts.

At present, *JEI* is undertaking a formal evaluation to assess how the journal impacts student understanding of the scientific process. Specifically, we are measuring how the review process affects students' interpretations of the scientific process and their own research. Anecdotally, we have observed positive outcomes from student-authors. This sentiment is most clearly described by one of our student-authors, who said: "I really appreciate all the helpful suggestions of the *JEI* editorial team, which helped to shape and polish the manuscript to its present state. It would not have been possible without *JEI*'s behind-the-scene help / guidance. It was a great learning experience." Moreover, we have heard from several teachers and mentors about their experience publishing with *JEI*. One mentor shared the following with us: "I serve as the managing editor for an Elsevier journal with a relatively high impact factor. I personally was very impressed by the quality of both the technical and editorial feedback provided by the *JEI* staff." A two-time student-author, wrote "It was a pleasure to work with *JEI* again on publishing a paper, and I will (hopefully) be pursuing environmental science in college and as a career in the future. I learned a lot from the experience, and I really appreciated the time and effort of everyone involved in helping me edit and finalize my paper." These sentiments reflect *JEI*'s mission: to help students understand the process of science and encourage them to continue to pursue science.

As *JEI* continues to grow, our aspiration is for it to serve as a broadly applicable and widely used tool in the science classroom and beyond. *JEI* will continue to provide a go-to resource for students to easily read reliable scien-

FIGURE 2. *JEI* publication statistics as of May 2015. (A) Number of publications each year from first publication in 2012 to May 2015. (B) Geographic location of published student authors from 2012 to May 2015. (C) *JEI* articles broken down by subject area.

tific information online and for teachers to include in their courses. Over time, we believe that the introduction of primary literature in the middle and high school years will demystify the scientific process and empower citizens of all ages to engage in responsible scientific communication.

SUPPLEMENTAL MATERIALS

Appendix 1: Reviewer evaluation form

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