Using Primary and Secondary Literature to Introduce Interdisciplinary Science to Undergraduate Students

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Abstract: Undergraduate students often lack opportunities to comprehend, present, and produce scientific literature as part of their regular curriculum. In courses that have already been already developed, students either analyzed a few journal articles and/or studied disciplinary content typically with the assistance of a textbook. In this study, I have developed a course that primarily relies on scientific literature to introduce interdisciplinary science in the intersection of biology and physics. Here, not only students learn content knowledge through literature, but also how to thoroughly analyze about 20 journal articles published in top-tier journals in the field. Students demonstrate their understanding of the content matter through weekly assignments, oral presentations, and a written review article.

Keywords: scientific literature analysis, interdisciplinary science, biophysics, DNA, scientific literacy

Introduction

Using primary literature to increase science literacy is used in different levels of classrooms from college-level introductory biology to graduate-level courses and has been the focus of many previous studies. In one study, students analyzed literature generating from the same laboratory over a period of time (Hoskins et al., 2007) and in another, students have studied a few articles in depth by learning how to dissect each section of the article (Janick-Buckner, 1997). In a third study, students in humanities were taught science literacy by analyzing one journal article of their choosing (Eslinger & Kent, 2018). Not only does scientific literature offer students a way to understand how a study is being performed, its hypothesis, methodology, and conclusions, but also teach them analytical skills to "follow a story," and to comprehend data through illustrations, graphs, and tables. Furthermore, students gain content knowledge supplementary to their coursework and textbooks. To that extent, many disciplinary courses have used selective primary literature as an introduction to scientific thinking *(*Kitchen et al., 2003; *M*uench*, 2000). However, there is a lack of use of scientific literature in interdisciplinary courses taught at the undergraduate level.* To address this void, I have developed a 3-credit course in biophysics that stresses interdisciplinary research in the intersection of biology and physics through intensive use of primary and secondary literature. Importantly, I used these articles to teach content knowledge in lieu of a textbook. In addition, students read an autobiography and a biography and watch documentaries to gain insight on ethics and politics behind major discoveries in the field. Furthermore, students write a comprehensive review article based on the literature they have read during the semester to gain further understanding and experience of producing scientific literature.

Methods

The target student population were upperclassmen who completed two semesters of biology and/or two semesters of physics. Out of the 66 students who completed the course during its three iterations, about 15% were non-biology majors (physics, engineering, education, psychology). Students could enroll in the course either as a biology or physics course.

The theme of the course was biophysics of DNA nanotechnology. Although the majority of students who completed this course learned basic biology and physics principles through the pre-requisites, I held short review sessions of major topics needed for the course such as DNA replication and optics. The physics reviews often included hands-on activities such as finding the index of refraction of water. While these concepts were familiar to students, interdisciplinary biophysics topics such as DNA origami, Atomic Force Microscopy, nano-robots, and magnetic tweezers were learned through primary and secondary literature. I introduced interdisciplinary topics such as the use of optical tweezers on DNA through short videos before students read any literature about the subject familiarizing them to nomenclature and the techniques.

In addition, some class periods were used to discuss the two books and the documentary. Students read the first book towards the beginning of the course, *The Double Helix: A personal account of the discovery of the structure of DNA* by James Watson. It is a candid autobiography on the discovery of the structure of DNA from Watson's impressions on Francis Crick to his opinions on Rosalind Franklin. Towards the middle of the semester, I assigned students to watch the documentary *Cracking the Code of Life* (2001) on PBS Nova about the Human Genome Project. In the last half of the semester, students read *Rosalind*

Franklin and DNA by Anne Sayre which is a biography of Franklin authored by her friend. I assigned readings on several chapters of the books per week and as a class, discussed ethics, humor, interdisciplinary nature of science, and politics behind each book and similarly on the documentary. Students were eager to share their thoughts which made it possible for lively discussions. Anecdotally, these discussions and the reflection papers students wrote enhanced their understanding on various aspects of producing scientific literature from how authorship is decided, how funding is secured, the ownership of science, the human aspect of scientists, and rivalries between scientific entities.

Scientific literature

As stated previously, the main aspect of this course was learning interdisciplinary science through scientific literature. Students were evaluated through two group presentations on research articles, take-home assignments based on these articles, a written literature review article, and three reflection essays based on the two books and the documentary. Since the theme of the course was biophysics of DNA nanotechnology, the first primary research article of the semester was the article that predicted the structure of DNA (Watson & Crick, 1953). I assigned students to read the article outside of class and to annotate; and used one class period to discuss the article from how it is structured to its content. The first secondary research article of the semester discussed three techniques used in biophysics to investigate biological molecules: Atomic Force Microscopy, Optical Tweezers, and Magnetic Tweezers (Neuman & Nagy, 2008).

The group presentations were broken into two categories: a PowerPoint presentation and a poster presentation. During the first half of the semester, I selected primary and secondary research articles based on biophysical studies of DNA nanotechnology that have used one of the three above mentioned techniques. Students presented in groups of two as 30-minute PowerPoint presentations. Each week, they completed a take-home assignment based on the articles/presentations of the week.

A sample of questions were:
1. Fig 4b shows displacement vs. time of the nano-robot movement. What information can we gather from the slope(s) of this graph?
2. What characteristic of an object (cantilever or DNA) is given by its spring constant?
3. In class, we talked about the Hooke's Law. Explain in 70-90 words how Optical Tweezers are used to obtain force-extension measurements of DNA.
4. What's "Brownian motion" and how is it different from the nano-robot movement in DNA origami?

The second half of the semester, I let student groups choose their own articles to present as posters, given that it fits within the theme and the techniques of the course. Students presented in groups of two, and each student was expected to invite at least one outside faculty member to attend the poster session, where only one poster was presented during a 50-minute class period. Therefore, for the 18-student class, there were nine poster sessions. The rest of the class attended the session along with invited faculty. Moreover some students invited their friends to attend the session, and on some occasions, additional faculty members saw the poster being presented and stopped by. The poster sessions were held in a room other than the usual classroom and I had instructed students not to gather around the poster as large groups, which let the presenters explain the poster multiple times during the time period. Usually, if there were five or six visitors to the poster, students waited their turn. After a few poster presentations, I noticed that each student would attend the session at a chosen time, some would attend at the beginning, and some would attend 30-minutes into the class period. Each presentation accompanied an assignment, and students who were not presenting spent the class time working on the assignment when they were not attending the poster. Prior to this course, some students did not know the purpose of a poster or how it is a medium for dissemination. Only one or two students in the class had attended a conference beforehand, therefore many students did not have an understanding of what a poster session entails.

As mentioned above, students completed a take-home assignment based on each poster. As opposed to detailed questions about the articles presented in PowerPoint, these were "big picture" questions about the study.

A sample of questions were:
1. What is the purpose of this study?
2. What were (if any) the previous studies that led to these experiments?
3. Pick two figures from Figs 2, 5, and 6 and explain each in 100-150 words.
4. If you were to follow-up on this work, what would you research on?

Before the start of poster presentations, I held a "poster workshop" where I shared sample posters from my own research and critiqued them. I let students work on their posters for the rest of the class time while I assisted with their designs and layouts. Furthermore, student groups met with me prior to their presentations so that I could give feedback on their PowerPoint slides and posters and clarify any content questions they may have. Some groups met me with complete presentations while others had only a layout. After each PowerPoint and poster presentation, the rest of the class did anonymous peer-evaluations and grading based on a rubric. These were later shared with the presenters along with my feedback. Grades for the presentations were based on the following factors:

1. Comprehension and explanation of the article
2. Organization of the presentation
3. Aesthetics of the PowerPoint slides or the poster
4. Confidence, enthusiasm, and handling of questions
5. Audience interaction

Towards the end of the semester, I guided students to write a literature review article based on the course theme. At this point in the semester, students had read a few review articles, therefore they knew the difference between primary and secondary articles. I selected two peer-reviewed journals (one biology and one physics) and guided students on how to find journal guidelines. They had the choice of writing their review article to be hypothetically submitted to one of the two journals. To assist with their review article, at first, I asked students to select a topic based on the course theme and to write a skeleton of the article. After obtaining my approval for the skeleton, students searched for suitable journal articles through the university library in addition to the ones we have already read. I assisted with at least two edits per student before their final submission.

Results

Students read 20 assigned articles during the semester, not including the additional literature they researched to write the review article. I conducted pre- and post-tests based on a primary research article describing a synthetic DNA walker (Shin & Pierce, 2004). Students completed the pre-test during the first week of classes, and an identical post-test during the last week of classes. We did not discuss this particular article during the semester. The mean score for the pre-test was 51.8% while the mean score for the post-test was 81.8%. Statistical analysis were done using a paired t-test which showed significant gains with $p = 2.32 \times 10^{-8}$ and $t = 1.77$.

A sample of questions were:

1. What is the 'point' of this article?
2. What is a bipedal DNA walker?
3. What techniques did the authors use to monitor the walking movement?
4. What is the difference between Fig 1a and Fig 1b?
5. In Fig 3, the purple line shows that the fluorescence decreased between time 1000 and 5000 seconds. Why did the fluorescence decrease?

At the end of the semester, students were given an anonymous survey about their experience in the course, which they answered in a Likert Scale. For questions, "Prior to taking this course, I was familiar with the basic biology related topics discussed in this course," and "Prior to taking this course, I was familiar with the basic physics related topics discussed in this course," students responded with ratings 4.17 ± 1.25 and 3.78 ± 1.17 out of a 1 – 5 scale, where 5 is "strongly agree." On the question "Prior to taking this course, I was familiar with the biophysics topics and methods discussed in the class," students responded with a much lower 1.67 ± 0.91 rating [Table 1]. It is clear that they were familiar with the basic disciplinary content knowledge prior to taking this course, but were not familiar with the interdisciplinary content introduced through scientific literature

As discussed previously, comprehending, presenting, and writing interdisciplinary literature is emphasized in this course. For questions, "I feel more confident about comprehending an interdisciplinary scientific article after having taken this course," "I feel more confident about presenting an interdisciplinary scientific article after having taken this course," and "I feel more confident about writing a scientific review article after having taken this course," student ratings were 4.50 ± 0.71, 4.56 ± 0.51, and 4.00 ± 0.77 respectively [Table 1]. These results show that students felt more confident on understanding, presenting, and producing interdisciplinary science than prior to taking this course.

The following rankings and comments show that overall, students were positive about the nature of the course. Students rated questions "The nature of this course comes very close to what I think of as interdisciplinary science," and "This course made me aware, understand, and/or think about ethics and politics in science" with 4.33 ± 0.59 and 4.17 ± 0.71 ratings, respectively. In addition, students rated the questions "This course piqued my interest in biophysics," and "I would recommend taking a course of this nature for all science students" at 4.17 ± 0.86 and 4.33 ± 0.97 respectively [Table 1].

Prompt	Mean Score
Prior to taking this course, I was familiar with the basic biology related topics discussed in this course.	4.17 ± 1.25
Prior to taking this course, I was familiar with the basic physics related topics discussed in this course.	3.78 ± 1.17
Prior to taking this course, I was familiar with the biophysics topics and methods discussed in the class.	1.67 ± 0.91
I feel more confident about comprehending an interdisciplinary scientific article after having taken this course.	4.50 ± 0.71
I feel more confident about presenting an interdisciplinary scientific article after having taken this course.	4.56 ± 0.51
I feel more confident about writing a scientific review article after having taken this course.	4.00 ± 0.77
The nature of this course comes very close to what I think of as "interdisciplinary science."	4.33 ± 0.59
This course made me aware, understand, and/or think about ethics and politics in science.	4.17 ± 0.71
This course piqued my interest in biophysics.	4.17 ± 0.86
I would recommend taking a course of this nature for all science students.	4.33 ± 0.97

Table 1: Results of the anonymous survey conducted during the last week of the semester (n = 18)

The comments were:

"I learned a lot more of the history and politics behind scientific endeavors than I thought I would, which I am grateful for as it shows the scientific process under a different light."

"I now understand how to analyze and interpret dense papers and use the information in a valuable and beneficial way."

"I have really enjoyed this course because of its practicality. It has helped me refine skills that I know will benefit me throughout my academic and professional career."

"I now am better at reading, dissecting, and understanding difficult primary articles and their information and figures."

"I was able to learn how to create a poster which I think will be a valuable skill in the future."

"I learned how to research different topics [online] and how to optimize my searches."

"I knew about DNA structure and interactions, but I didn't know how we knew this info, so this class was really eye-opening for me in that sense."

Discussion

Anecdotally, during the first half of the semester, some students were nervous about presenting an interdisciplinary article to the class. However, during the second half of the semester, students were confident and looked forward to the poster presentations and took ownership of the article they had selected. There were 18 class periods dedicated to PowerPoint and poster presentations, and compared to the first few weeks of the semester, students asked better questions from the presenters as the semester progressed. This elevated students' critical thinking and analytical skills whether they were the presenters or audience members. Assignments based on each article as described earlier solidified the students' knowledge on each presentation. Many students were initially not confident on writing a review article, and I spent a significant amount of time towards the end of the semester helping them with the edits. But over time, they became more confident and produced better drafts. After the semester was over, I selected one of the better submissions to be further edited and submitted to a peer-reviewed journal, which is now published (Arora & de Silva, 2018).

From the pre- and post-test results it is clear that students learned to comprehend interdisciplinary science through primary and secondary articles.

Furthermore, from student perceptions, this course is a fun way to learn interdisciplinary content while acquiring oral and written communications skills. Anecdotally, many other students have asked me about this course and when I would be teaching it next. They had heard about it from their peers who had recommended the course.

A course of this nature could be developed for any interdisciplinary science from biophysics to biopsychology depending on the expertise of the instructor. Here, instead of traditional lectures, upperclassmen self-learn material by reading, presenting, and producing science literature in addition to being exposed to ethics and politics of science. The instructor's role is to introduce basic material and then to guide students to comprehend relevant research articles in order for them to gain further knowledge on the subject. By presenting self-taught material in PowerPoint and poster forms to their peers, students learn to present in the two most common mediums of dissemination at conferences. Additionally, instead of passive learning that is emphasized in traditional science classrooms, this course encouraged students to be active learners while take ownership of elevating their skill sets. The course was offered three times as a special topics course both in biology and physics and is now a regular course in the course catalog. The first two times the course was offered, the enrollment was 24 students each time, but for the third iteration, the number of students was reduced to 18 to allow more in-class discussions, presentations, and better student-instructor interactions.

Acknowledgements

This study (H1804093) has been approved by the Mercer University Institutional Review Board.

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