“Science has always been about asking questions”: Critical Science Literacy in STEM Writing

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During my (Holly’s) first teaching job in Chile, *mi hermana anfitriona* introduced me to a Spanish idiom, “*tener buen lejos*,” which means something or someone looks good from a distance but becomes less attractive once you get a closer look. For many diverse students, STEM fields are initially attractive, but the actual experience of entering a STEM field often results in underrepresented students being disparately turned off and turned away. Biology instructors at our own university are aware of opportunity gaps in their introductory survey courses, which have impacted access to STEM fields for students who are historically underrepresented in STEM majors, and these instructors have even actively researched and implemented opportunities for change. One of their published studies specifically recognizes the following:

> Underrepresented minority (URM) students in the United States . . . start college with the same level of interest in STEM majors as their overrepresented peers, but 6-[year] STEM completion rates drop from 52% for Asian Americans and 43% for Caucasians to 22% for African Americans, 29% for Latinx, and 25% for Native Americans (Theobald et al., 2020, p. 6476).

While STEM faculty have focused on mitigating disparate impacts on student attrition based on *achievement* to provide greater access and opportunities in STEM, we focus on *experience* for the same purposes. Both Dhatri Badri’s vignette and a journal entry from Alicia Bitler and Ebtissam Oraby’s chapter in this volume have highlighted the role that a single course can have for students in situating themselves and their chosen STEM field. Badri related how bridging the gap between her place in STEM and her experience as a woman of color helped her to engineer her own inclusion, while the journal writer in Bitler and Oraby said that recognizing cultural situatedness led to understanding her discipline better. To these insights, we add a chorus of student voices on how and to what extent these

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acts of bridging, engineering, situating, and recognizing knowledge and identity within a single course can impact student experience.

This chapter describes our journey as writing instructors situated within a disciplinary writing program to propose and teach a course entitled Critical Science Literacy in the Natural Sciences. This chapter attempts to synthesize some of the theoretical strands that feed into the critical science literacy (CSL) framework and describe the course we designed to enhance students' capacities for critical inquiry into their own disciplines. Such capacities can facilitate students' identities as scientific practitioners, which can then enhance their agency and feelings of legitimacy as communicators and can also enable them to critique and disrupt from within disciplinary structures that have caused historical exclusion or harm. Consequently, CSL can better support students across diverse backgrounds who are working toward a degree, and eventually a career, in the natural sciences. In this chapter, we describe the theoretical underpinnings of CSL and how our institution and program contexts revealed a need for CSL-based curriculum. We then offer an overview of the course itself and finally reflect on its successes and possibilities based on student survey data.

The Framework: Critical Science Literacy

We have adapted the concept of CSL from Susanna Priest (2013) and Maria E. Gigante (2014), who developed the concept in response to the social turn in the natural sciences and to increasing lay publics' participation in science. Priest highlights the social and cultural nature of science, writing that scientific knowledge includes "the kind of everyday, tacit knowledge of 'how things work' that members of a culture take for granted but outsiders can find mystifying" (p. 138). The other key piece of Priest's definition is the civic importance of scientific knowledge: citizens need to be able to "sort out which truths should be relied on in any given moment" (p. 138). These "moments" of reliance on science have proliferated in part because of the grave stakes of issues like climate change and global pandemics and because of the multitude of public-facing platforms on which scientific debates now play out.

Gigante (2014) takes up Priest's version of CSL but expands its role in undergraduate science education. Gigante calls on specialists in writing studies, rhetoric of science, and science communication to help introduce CSL because undergraduate survey science courses do not often focus on how "scientific culture operates," nor are students typically "prompted to take responsibility for communicating their research to nonexpert publics" (p. 78). Personally and professionally, we can attest to a growing necessity for scientists to be able to communicate with different kinds of publics. Gigante asserts that a key element of CSL is rhetorical knowledge and suggests that "a rhetorically grounded science writing course can assist science majors with understanding the intricacies of scientific communication" within and beyond science (p. 79). We argue that CSL can help expose what Jennifer Mallette describes in this volume as "tacit requirements and expectations" in science, which "can serve to widen gaps between students with and without access to stronger preparation in writing, better mentoring, or effective peer educational networks" (this collection). Additionally, CSL can help students recognize and, we hope, disrupt what Jameta Barlow and Kylie Quave (this volume) term "white empiricism" and other "inequitable forms of knowledge production" in STEM (this collection).

Whether or not they do so deliberately in their claims that science is social, civic, and rhetorical, Priest and Gigante evoke "threshold concepts" in biology. Jan H.F. Meyer and Ray Land (2012) define a threshold concept as "a transformed way of understanding, or interpreting, or viewing something without which the learner cannot progress" (p. 3). Threshold concepts in a discipline have certain characteristics: they transform understanding, are irreversible (once you know, you cannot unknow), are integrative (that is, they reveal interrelated ideas), are bounded, and are potentially troublesome. "Troublesome" knowledge can refer to the conceptually difficult or tacit, which is why grasping a threshold concept can often be accompanied by an "Ah ha!" moment.

Charlotte Taylor (2012) notes that threshold concepts in biology can be difficult to generalize because there are so many far-flung subfields that comprise the biological sciences, all with different foci and methods: environmental, cellular/molecular, marine, biochemistry, physiology, evolutionary, genetics, etc. Speaking broadly, however, she found that threshold concepts in biology tend to be interrelated, and deeper understanding comes from link-building (examples include the complexity of living systems, probability and uncertainty, consequences of meiosis, and creating hypotheses). The webbed, cumulative nature of scientific knowledge creates challenges for teaching undergraduate biology courses, and these challenges may lead to pedagogies that are more focused on "fact-transmission" than on the contexts, cultures, and processes of science (Taylor, 2012, p. 90; see also Weinstein, 2009).

Threshold concepts from writing studies relevant to CSL are that writing is a social and rhetorical activity and that writing enacts and creates identities and ideologies (Adler-Kassner & Wardle, 2015). These understandings have been called for and cultivated by every contributor to this volume as we recognize the situatedness of science knowledge across time, space, and identity. Of particular interest to us as writing instructors is the role of language in learning science because, first, many scientific discourses can be technical and specialized and difficult to learn, and second, because scientific language varies so much as its audiences and stakeholders shift. Meyer and Land's (2012) characterization of the role of language in the threshold concepts framework is helpful:

> Specific discourses have developed within disciplines to represent (and simultaneously privilege) particular understandings and ways of seeing and thinking. Such discourses distinguish individual communities of practice and are necessarily less familiar to new entrants (p. 14).

Not only is language characterized as a layer of difficulty (an aspect of "troublesomeness") in achieving a threshold concept, but the passage also alludes to power relationships inherent in learning disciplinary discourse. We propose that CSL acknowledges (the learning of) scientific discourse(s) as its own threshold concept, particularly in the sense that discourse is something "without which [students] cannot progress" (p. 14) within the discipline. Facility with discourse should not be limited to mastery of terminology but should include recognition of the highly rhetorical and hierarchical nature of scientific discourses. To that end, CSL includes the ability to move across multiple discursive channels because communicating in science often involves acts of translation and accommodation (Fahnestock, 1986).

Learning disciplinary discourse also involves moving through certain kinds of communities and cultures. To learn science—to learn to *be a scientist*—is in large part a process of language learning, but one that includes "not merely knowledge of form, but knowledge of the rhetorical requirements of that form and of the writing behaviors common to professional scientists" (Poe et al., 2010, p., 23). Cultivating what Mya Poe, Neal Lerner, and Jennifer Craig call a "scientific discursive identity" can be challenging, given that it requires understanding "the *social significance* of appropriating scientific discourse in interpersonal and intrapersonal contexts" (Brown et al., 2005, p. 781; emphasis added). Scientific texts *have* social significance to the degree that they conform to certain tenets, such as objectivity, certainty, and authority (or, read another way, exclusion). The more technical or specialized a discourse, the more difficult it may be to enter into because, often, these discursive practices are so different from the kinds of literacy practiced in personal lives and communities (Adler-Kassner & Wardle, 2015). This leaves us with questions about the ways that scientific discourse occludes subjectivity, uncertainty, and exclusion based on difference.

As we developed our own CSL course, we wished to focus not only on the rhetorical and social aspects of science and its discourses but also on the ways that these knowledges have traditionally harmed or excluded certain groups; the ways that scientific texts have suppressed, sterilized, or rationalized that harm; and the ways that scientific practice and communication have discouraged a sense of belonging among those with ostensibly conflicting cultural frameworks and literacy practices. That is, we wanted to lean into the *criticality* of CSL. To build a more capacious CSL, we borrow from Allan Luke's (2012) work on critical literacy (distinct from

CSL and from the phrase "critical thinking" commonly used in K-12 teaching and learning contexts), a framework that entails:

> a) a focus on ideology critique and cultural analysis as a key element of education against cultural exclusion and marginalization; b) a commitment to the inclusion of working class, linguistic, and cultural minorities, indigenous learners, and others marginalized on the basis of gender, sexuality, and other forms of difference; and c) an engagement with the significance of text, ideology, and discourse in the construction of social and material relations, everyday cultural and political life (p. 6).

Many in the various but interlocking fields of Science and Technology Studies (STS) have written of the ways that scientific practice has lent itself to the kinds of critiques Luke enumerates here (Epstein, 2007; Nelson, 2016; Roberts, 2011; and TallBear, 2013 are but a few examples). We try to feature, whenever possible, these critiques in our courses.

In sum, we embrace Priest's emphasis on the social and civic nature of science and Gigante's emphasis on science as rhetorical. In our own development of a CSL course, we also focus on the ways that scientific discourse can suppress human bias and the very real repercussions that bias can have on material conditions and embodied experience. Because acquiring a new discourse is like taking on a new identity, we aim to teach skills in rhetorical analysis, but in critical terms, and ask constantly how scientists' experiences and positions shape how they conceive of and communicate science. Our ultimate goal is to work against the "weed out" culture so commonly seen in undergraduate science programs; just as advocates are pushing for more human-centered approaches for the stakeholders of science (patients, consumers, citizens), this course seeks to create communities of belonging for young scientists themselves.

The Context: The Institution and the Program

The University of Washington is a public Research I university located in Seattle. As of autumn 2022 (UW is on the quarter system), the flagship Seattle campus enrolls over 48,000 students, including 33,000 undergraduates. About 26 percent of its students hail from Washington State, and 11 percent are international students; 36 percent of students identify as Caucasian, 24 percent as Asian, 9 percent as Hispanic/Latino, 5 percent African American, and about 1 percent each as Hawaiian/Pacific Islanders and American Indian. The most popular majors include computer science, business administration, psychology, biochemistry, and electrical engineering, and 48% of students occupy STEM majors (University of Washington, 2022).

Competition for admission into many STEM majors at UW can be intense, which makes for a high-stakes experience. Demand for STEM majors has increased so much in the last decade that students must apply for acceptance to the most popular majors, though acceptance rates are highly variable; for example, nearly 100 percent of the 550-600 students who apply to the biology major are accepted, whereas over 7,500 students named computer science as their top choice for a major, but there are only 550 spaces per year (Stiffler, 2022). While the numbers for the biology major seem reassuring on their face, one staffer from the department admitted that the introductory courses serve a "weed out" function, which prompts questions about the forms of gatekeeping students experience as they progress toward (and through) their majors. Additionally, persistently low funding from the state and increased reliance on funding from industry (UW is among the top ten universities receiving industrial support in the US) have led to a STEM-oriented culture on campus that is felt across disciplines and departments.

The Program for Writing Across Campus (PWAC)[1] offers disciplinary writing seminars in two different formats, linked and unlinked. The linked courses (the majority of the courses we offer) are each connected with large lecture courses in a wide variety of disciplines that range from philosophy to biology (we offer writing courses linked with several of the institution's most popular majors listed above). Only students enrolled in the lecture course are eligible to take the linked writing course. In recent years, PWAC has been offering a growing number of unlinked discipline-specific courses: writing in the humanities, writing in the social sciences, technical writing, and CSL. While all our courses satisfy the general education Composition and Additional Writing requirements, they are not required for any major or program. Students seeking to satisfy their writing requirements in discipline-specific contexts tend to gravitate toward our program rather than taking general composition courses.

All PWAC writing assignments and scaffolding activities are designed to cultivate students' knowledge of the topics, genres, and methodologies of the lecture course (or discipline) with which it is linked. PWAC instructors, as writing rather than content experts, help students orient themselves in a particular field and orienteer themselves toward developing disciplinary writing identities. This specificity of writing contexts enables PWAC instructors to develop inquiries surrounding students' writing and learning that are infrequently addressed in other institutional contexts.

The unlinked CSL course we present in this chapter was first conceived based on the observations, experiences, and critical conversations among three biology-linked writing instructors (one of whom is Holly) and, later, with the PWAC director (Megan). BIOL 180 is the first of a three-sequence introductory set of biology courses,

1 The program was formerly called The Interdisciplinary Writing Program, but the name was changed in 2022. Data for this chapter were collected prior to the name change, but for practical purposes, we use the new name here.

which regularly enrolls 600-800 students, mostly sophomores (Brownell et al., 2014; Haak et al., 2011). Students must pass these courses to continue major coursework in biology. The department has taken steps to fill opportunity gaps based on class structures/activities and measuring student achievement scores quantitatively; however, qualitative student experience has not been considered during these studies.

As an anecdotal insight into potential student experience, two PWAC instructors (Holly and Hsinmei Lin) observed the first day of class in BIOL 180. One slide from the lecture dealt with defining science in contrast to pseudo-science and religion. In the scenario, someone had crashed on a bicycle, and the wounds were now healing. Students were asked to explain the healing process according to science ("The blood clotted to form a scab, and now my cells are regenerating skin."), pseudo-science ("I was wearing my lucky shirt, so I made it through."), and religion ("I prayed, and a higher power healed me.").

For the PWAC instructors, the scenario established a straw-man argument where pseudo-science and religion could be simplified, essentialized, caricatured, and knocked down easily in contrast to science. Hsinmei noted that pseudo-science is often used as a colonizing proxy term for Indigenous Traditional Knowledge (TK) and/or Traditional Chinese Medicine (TCM), which was part of her own cultural background. Holly reflected on her own extended identity crisis when she was told by her undergraduate science instructors that there was no room for her faith tradition if she were pursuing science and how she later discovered that many famous scientists did, in fact, draw on their faith traditions to animate their work in science. Underrepresented students could feel that important and complex aspects of their identities are not welcomed in disciplinary coursework even when active learning components are implemented structurally.

Student identity and experience are important for understanding inclusion but were not addressed by the Biology Department studies. It is worth noting that some of the structural changes implemented by the Biology Department still provided hope for greater access in STEM courses, so we will briefly overview some of the key findings based on their framing around "achievement" (even though "opportunity" may be a better framework for placing responsibility on the program, rather than students, for disparate results and access). Theobald et al. (2020) note that grades in STEM courses are heavily dependent on exam scores, so exam score "achievement gaps" (in the language of the Biology Department) create a barrier for URM students when grades fall below the threshold that allows for continued study or if students decide themselves to withdraw. The research team was able to show that active learning reduced "achievement gaps" in exam scores by 33 percent and passing rates by 45 percent. Overall, they propose that deliberate practice and a culture of inclusion are the two key elements to reversing achievement gaps in STEM courses.

If active learning increases opportunities for URM student success, what does this active learning look like? David C. Haak et al. (2011) show that high-structure classes with pre-reading quizzes, informal class group work, and multiple-choice clicker or random call questions were able to halve the "achievement gap" observed in traditional lecture-based class structures. Questions that prompted students to engage higher levels of Bloom's taxonomy and opportunities for group work where students could co-construct knowledge were crucial. Sara E. Brownell et al. (2014) explain that experimental design is a fundamental skill and an important aspect of science literacy and critical thinking. Asking students to analyze an experiment OR design an experiment using worksheet prompts as a group for 30 minutes during class led to more accurate conceptions of sample size and repeating an experiment. In addition, Sarah L. Eddy et al. (2015) identify several dimensions that can be used to evaluate a class's overall active learning elements for students: does the class create opportunities for student practice, logic development, accountability, and reducing student apprehension?

All of these studies identify aspects of STEM content courses that can reduce differential passing rates for underrepresented students based on exam scores. However, constraints remain in the learning system overall related to class size, time, content, instructor training, etc., and as noted before, the studies do not collect or address actual student experience.

To return to the anecdotal example of defining science, a more complex and inclusive understanding of science would mean shifting away from a framework of "evidence-based teaching" and toward a pedagogical and curricular emphasis on belonging and equity (see Mallette, this volume). To do so means examining the underlying values and activities of a scientific community, such as asking questions and making systematic observations, rather than setting science in conflict with other knowledge systems or ways of knowing. It would also mean asking students to identify what parts of their own backgrounds contribute to the ways they approach or participate in science, which is how Holly and Hsinmei, as writing instructors, expanded this conversation in their own linked writing classes.

The authors of this chapter recognize that writing courses have unique potential to emphasize elements identified as important for underrepresented student success in BIOL 180 research, such as practice, logic development, and reducing student apprehension and feelings of exclusion. By foregrounding the nature of science and the positionality of its practitioners, CSL can enhance students' feelings of inclusion in STEM courses (and fields).

The Course: Critical Science Literacy in the Natural Sciences (ENGL 296)

After observing the ways that undergraduates were moving toward and through natural science majors, we saw the need for a course that supplemented (and, ideally, reframed) students' apprenticeships in the sciences. We named the course "Critical Literacy in the Natural Sciences," hoping to capture the theoretical investments we have described and also hoping to market the course to (current or aspiring) science majors looking to satisfy a composition requirement. In planning discussions, the authors (Megan and Holly), along with a doctoral student in biology, Aric Rininger, developed a curriculum where students would learn to become confident, authoritative participants in science and scientific discourse while at the same time becoming familiar with the ways that Western values are embedded and centered (often invisibly) in the sciences and its related institutions. Through course content and culturally responsive, anti-oppressive pedagogies, the course aims to help students interrogate these values as they enter advanced study.

Like all PWAC courses, our CSL course implements pedagogical approaches that our program holds dear: students work with a variety of texts, including primary and secondary scientific texts as well as their own and their peers' writing. Throughout, they move through cycles of reading, discussion, reflective and formal writing, peer review, conferencing, revision, and intensive instructor interaction and feedback.

The course is organized around three broad learning goals, listed below, with narrower, orienting questions following each goal. In this course, and as we spell out explicitly in the syllabus, students will work toward the following:

Understanding the nature of science as contingent, contested, and situated.

- What purpose does science serve? Does it have social or moral responsibility?
- How are questions formulated and answered in the sciences? What kinds of questions can science answer? Why do people choose particular questions in science, and how do they develop hypotheses? What socio-political and ethical values underlie scientific assumptions, questions, and hypotheses?

Engaging a diversity of ways of knowing and doing in science across cultures and nations, including identifying strengths and limitations of different approaches.

- What are essentialist vs. holistic ways of knowing in science?
- How do scientists situate the self in relation to various communities (academic, professional, disciplinary, cultural, national, indigenous, etc.) and ecologies (environmental, institutional, research contexts, topics/objects of inquiry)?
- By what means can students locate themselves within scientific practice and discourse? What kinds of cultural and intellectual capital do they bring to the course, and might they bring to scientific inquiry?
- How can students deploy a critical lens as they navigate scientific fields first as apprentices and then as professionals?

Tracing the genealogies of ideas in circulation as information moves through pipelines and networks.

- How do scientific concepts and "discoveries" get reified as they are communicated across various platforms? How do reified concepts privilege or harm certain groups? How does "reality" differ across those groups?
- In what ways can novice scientists use transformative communication practices within a realm where the language of Western mainstream science is dominant?
- How can inquiry into scientific content provide occasions for writing to learn as a form of reflection and engagement? Equally important, how can communicating scientific content provide occasions for learning to write in order to share that knowledge with particular audiences?
- How can intertextual connections across time and space provide greater insights into particular "facts"?
- In what ways can scientific communication practices (both traditional and transformative) serve as a vehicle for responding to all of the above questions?

According to the American Association for the Advancement of Science's Benchmarks for Science Literacy (1993), "Students should learn that all sorts of people, indeed, people like themselves, have done and continue to do science" (n.p.). These students bring a huge diversity of cultural and intellectual experience to their studies but may not always feel that non-Western ways of knowing and practicing are embraced (or even acknowledged). UW's STEM education is seen internationally as second to none, but our undergraduate and postsecondary programs encounter the same pipeline issues that the sciences face globally: women, people of color, and indigenous populations are dropping off of scientific career pathways because scientific fields are not sufficiently culturally responsive (Grunspan et al., 2016). This course aims to help students become aware of these hierarchical traditions and to enable them to critique and transform traditional approaches to doing science.

After developing the course in 2019 and submitting it for the formal course approval process, the English department chair informed us that, while he loved the course, we would need to present the syllabus at a meeting of department chairs in the Natural Sciences division of our College. This was a courtesy expected of any department developing a course out of their disciplinary wheelhouse: as English faculty, we needed to get the science department chairs' blessing to offer a course situated in the sciences.

As program director, Megan prepared to present at that meeting and did so somewhat apprehensively. After all, the idea for the course first came about after we had been observing survey science courses with some concern. While our course contains no explicit critique of the science curriculum at our institution, it *does* critique some of the traditional methods and assumptions embedded in science generally. We were surprised and delighted, however, to hear rave responses from the science chairs. They explained that their own major curricula were so packed with content that they had no time to explore issues like the nature of science or uncertainty, subjectivity, or racism in science. The only concern they brought up was that there was no way we would be able to serve hundreds of natural science majors in a given year. Indeed, with classes capped at 23 (as most composition courses are at UW) and at three sections a year, we are lucky if we can serve 70. Still, we were pleased to move forward with the course, and we have been offering about one section per quarter, three to four quarters per year, since 2019. Below, we describe our three major assignment sequences, along with reflections on the assignments' strengths and suggestions for adapting them.

Project 1: Tracing the Life of a Scientific Fact

This assignment draws its inspiration from Jeanne Fahnestock's classic (1986) article, "Accommodating Science: The Rhetorical Life of Scientific Facts," in which Fahnestock analyzes rhetorical shifts as scientific articles are translated from specialized research reports to public-facing summary articles. In this project, students select a topic or event (the Rover landing on Mars and the U.S. arrival of the Asian giant hornet, aka "murder hornet," are two recently selected topics), typically finding the item on a social media platform like Twitter and collecting publications translating the study on different platforms until they trace it back to the source, a peer-reviewed research article.

Students analyzed the ways that authors' rhetorical strategies (e.g., tone, voice, use of images and layout, etc.) changed across publications and then presented their analysis in Adobe Creative Cloud Express (formerly called Spark), a free online program for producing multimedia content. The program is accessible and user-friendly and offers a platform for integrating images, text, and other media, which in turn encourages deep analysis of visual, textual, and digital rhetorics. We have found that students not only become more able to demonstrate how the writing occasion and audience expectations shape the ways that "facts" get represented in texts, but they also come to question the very nature of a scientific fact. If a tweet attempts to capture attention and persuade, then so does an article in *Nature*, in its own way. The assignment also has the added benefit of cultivating media literacy and research skills through the "tracing" process (see Megan's version of the prompt in the Appendix).

Students report through assignment debriefs, mid-quarter check-ins, and course evaluations that learning about the ways that information changes as it is translated across platforms is transformative for them. We find it to be an especially successful assignment at the start of the quarter because it sets up a foundation for students' understanding of accommodation for different rhetorical situations and the stability (or rather dynamic nature) of scientific knowledge, which informs their future thinking and writing. Additionally, it is a creative, low-stakes "writing to learn" assignment that eases students into the next, higher-stakes project.

Project 2: Generating a Scientific Question

The second assignment sequence asks students to consider the scientific hypothesis and research question.[2] Where do research questions and hypotheses come from? What assumptions about reality are embedded within them? How does the formulation of a research question select certain realities and deflect others? We hoped, through this project, to pull back the curtain on the ideological dimensions that are presumed to be neutralized in scientific research.

In the first part of this project, students read and discuss an excerpt from Robin Wall Kimmerer's book *Braiding Sweetgrass*, where the author, a botany professor and member of the Citizen Potawatomi Nation, describes the question that brought her to a botany major as an undergraduate. She wrote, "I wanted to learn about why goldenrod and asters look so beautiful together"—to which her adviser responded, "That is not science," and "If you want to study beauty, you should go to art school" (2013, p. 39-41).

After guided discussion about what counts as science and what kinds of questions are legitimate, students then describe their own curiosities about the natural world (which are often the inquiries that drove them to science in the first place). Finally, they convert these questions into a formal research design proposal, sometimes writing toward a real-life targeted audience, such as the UW Mary Gates Research Scholarship. In the process of drafting, students examine real-life proposals and consider how their own inquiries must be (re)framed for the conventions of formal, institutional contexts.

While students report that this assignment has a lot of practical value—for many it is their first opportunity to compose in a genre that they will use professionally—we ourselves sometimes feel challenged to support it as fully as we can. Neither of us is a scientist. While we do guide students to think through tenets of experimental design like internal and external validity, replicability, etc., we are not able to guide them as well as we would wish (dilemmas about instructor expertise and authority are not uncommon in disciplinary writing programs). However, it gives students more time, space, and authority to apply principles of experimental design than during large survey courses and offers an opportunity to "learn to write" in a disciplinary genre.

2 UW quarters are approximately ten weeks long, and each major project is spaced roughly three weeks apart.

Our limitations in Western science give way to even greater limitations in other scientific traditions, such as indigenous science, holistic or “folk” approaches, or TCM. Some students bring with them immensely valuable cultural experience that they can juxtapose against Western frameworks, gaining a deeper understanding of each; other students do not necessarily possess such backgrounds. In future versions of the course, we hope to provide richer introductions to non-Western scientific frameworks. This might include guest speakers or field trips and certainly should include the hiring of instructors who can bring multi- or transcultural perspectives on science. Perhaps most important, we need to better facilitate cross-pollination among students—for example, by sharing former or current student writing—so they can benefit from each other’s immense intellectual and cultural knowledges.

During revisions of this chapter, we learned that PWAC instructor Christopher Chan, who has been teaching ENGL 296 in recent quarters, has updated this assignment sequence. He assigns an “ethnographic vignette” in which students are asked to “answer a question about how people conduct, live with, think about, talk about, experience, or contribute to science: a short, descriptive essay that illustrates a scene that you observed, and then uses this observation to explicate an answer for your question.” We love this adaptation and believe it responds directly to the course’s orienting question about how scientists situate the self within various communities.

Project 3: Science Literacy Narrative

All scientists have intellectual, cultural, and linguistic histories. For the (ostensible) sake of neutrality and objectivity, apprentices are trained to divorce themselves from these histories, especially when they are doing and communicating research. This assignment asks students to read examples of different types of scientists’ narratives, which reveal how personal history and professional practice can interface. Examples of such narratives include a 2019 op-ed by Katherine Hayhoe, a climate scientist and self-described evangelical Christian; Nobel Prize winner Youyou Tu’s (2011) narrative about how her cultural grounding in TCM enabled her to develop the anti-malaria drug that has saved millions of lives; and/or the documentary film, *Oliver Sacks: His Own Life* (Burns, 2020), about the famous neurologist and his struggles with homophobia and addiction.

Students also read the chapter “How Does Rhetoric Work in Multimodal Projects?” in Ball, Sheppard, and Arola’s 2018 textbook *Writer/Designer* to help them ground their choice of a genre that best serves their own scientific narratives. In their narratives, which have included podcasts, films, comic strips, photo essays, and medical school personal statements, students explore how their identities, investments, and intellectual interests have shaped their trajectories as scientists. Holly has used digital stories as a particular genre for the class in which students share their videos at a class showcase event. This assignment is a form of reflection and an orientation to/within the desired scientific field, but we also hope that it will serve as a form of self-advocacy—a confident declaration of intention to participate.

In Their Own Words: Student Survey Feedback

We wanted to be able to assess how we were achieving our learning goals, so we have administered a survey to each course section since we first offered it in the winter of 2020. We obtained IRB approval and collected responses anonymously at the end of the quarter, explaining that responses might be used in scholarly publication, that participation was completely optional, and that it had no bearing on course grades. Given its voluntary nature, we acknowledge selection bias may be at work in the responses. However, while generalizable patterns are helpful, even disparate responses are informative and offer possibilities for differentiated instruction. From the survey, which consists of seven open-ended questions, we hoped to gain a deeper understanding of the following broad questions, which organize the themes we discuss below.

- How did students' understanding of science as contingent, contested, and uncertain change while taking a CSL course?
- How did the course affect students' sense of belonging in the discipline?
- Did the course encourage students to make connections to other courses/learning occasions in the field?

Shifting Understandings

Of 32 responses to the question, "How has your belief in scientific certainty shifted?" 18 said that they had come to understand scientific knowledge as dynamic. As one representative response stated, "I think this class has pushed me to be willing to question the extent and limits of science." Of the 12 who said that their understanding of scientific certainty had *not* shifted, the belief went both ways: some students maintained their belief in scientific certainty; others (about three) maintained their prior belief in *uncertainty* (the course only affirmed it). These two responses stood out in their juxtaposition:

> My belief hasn't shifted because I'm queer, disabled and neurodivergent- bias in science affects me and my people to an extremely dramatic degree.

> No, I still believe that science is absolute. Although there may be bias, as long as the evidence is there, it is ok.

The first response shows awareness of the ways that identity and positionality affect beliefs about the nature of science. It is plausible that those who occupy traditionally marginalized identity groups are better positioned to embrace scientific contingency, just as those with non-normative cultural backgrounds seem better able to integrate multiple scientific frameworks (as we discussed above). However, it is hard to apply the logic in reverse since those who affirmed their belief in scientific certainty did not (could not?) attribute their beliefs to their own positioning. These observations only affirm to us the importance of asking students to share their own experiences and identities with the class community.

In addition to students' shifting perspectives on scientific certainty we observed a shift in their overall metacognition about the nature of science and scientific communication. In response to the multi-part question, "What were your goals for taking this class? Did these goals change over time? To what extent did the course align with your goals?" we noticed a pattern in which students said they initially wanted to "gain skills for scientific writing" (33 of 39 responses) and to "fulfill [the] general education writing requirement" (7 responses). A number of respondents (about 10) expressed a pivot not just in their scientific understanding but also in the kind of knowledge they viewed as important, some noting the unexpectedness of the shift.

> Over time, I became interested in the person behind the publication; what they're [sic] motives are or beliefs, etc. Having finished the course, I can say that I did align with the types of things that I wanted to learn. I want to be a more capable scientist, obviously, and I think that this course helped me more carefully define what "capable" means.

> To be honest, my main goal for taking this class was to receive my English composition credit. However, as the class continued, I realized that I really enjoyed the readings and discussions. This class has taught me to think in slightly different ways, and to—above all—ask questions.

Other students did not report such a shift, though we were satisfied to see that the course still met the practical goals students arrived with. We are reminded here of the writing to learn/learning to write duality of disciplinary writing instruction. The phrase "writing to learn" is shorthand for the idea that the very act of writing stimulates a deeper understanding of a given concept. "Learning to write" (or "learning to communicate") involves practicing composing discipline-specific genres (e.g., a research proposal), largely for the purposes of application in real-world contexts.

Good disciplinary writing courses involve both learning goals, but we were unsurprised that students may value "writing to learn" and "learning to write" differently, depending on their larger goals. The following responses show such different goals—one was self-understanding and intellectual challenge, the other professional preparation.

> I wanted to continue to understand who I was as a writer and develop my writing skills as a scientist. This class definitely challenged me to try things that I have never tried before, and I thought it really pushed me out of my comfort zone.

> I wanted to get better at reading and writing critical science literature to help prepare me for nursing school as well as a career in nursing.

Sense of Belonging in the Sciences

As our course goals indicate, an essential element of CSL is a sense of belonging in the sciences. Enhancing students' feeling of belonging in their future field helps address pipeline issues for URM students, but our hope, too, is that our students' sense of their own humanity as scientists will support their understanding that science is a social, human-driven enterprise.

Of 37 responses to the question, "Do you feel like you have a greater sense of belonging in the sciences after taking this course? Why or why not?" 22 said they felt a greater sense of belonging, five said no, and four gave a qualified response. Some of the explanations students gave for a greater sense of belonging include an expanded exposure to/interest in other classmates' areas of research, increased confidence in "involving myself in more opportunities related to science," an ability to read and write about science in new ways, feeling "more connected with science than before," and overcoming a "sort of 'imposter syndrome'." Some students responded that even though their sense of belonging was not affected, their knowledge increased. For example:

> I don't necessarily feel a greater sense of belonging, but I do feel a greater sense of understanding regarding scientific publications and communication in general.

> I'm not sure, I am more aware though of how exclusionary the current and especially the past fields of science have been towards anyone outside of white males.

One key finding that relates to students' belonging is their ability to choose their own assignment topics—in survey responses and course evaluation responses alike, this is one of the most highly lauded aspects of the course (as it is in our other science writing courses). Encouraging students to select their own writing topics may have had the unanticipated effect of cultivating a sense of belonging in the sciences for students, perhaps more than any other aspect of the curriculum, as this response illustrates: "Every single project I did directly related to something I was truly interested in. It made it so easy to write about something you care about and not just some essay prompt." We urge educators to allow student choice whenever possible in order to encourage student ownership of their own work.

Making Connections

The final question in our survey was, "What connections did you notice between your learning in this course and other courses? Are there frictions or tensions with learning in other courses?" As the subquestion shows, we considered it a very real possibility that CSL could challenge what students were learning in other science courses. The responses revealed a much more interesting picture. In fact, not only did some students see alignment between CSL and other science courses (6 of 33 responses), but many others (14 of 33) spoke about how this course and their other studies in science were mutually reinforcing. We were surprised and delighted to see that, for these students, learning transfer was so immediate and so visible. A couple representative responses include:

> This course helped me be more aware of the rhetorical situation and the audience my writing is addressing. This awareness helped me write to my audience better in other science classes. In addition, reading and researching more about scientific fields that interest me in this class helps me gain more interest and motivation in work for other science classes.

> Science has always been about asking questions, and this class has helped me ask myself more questions when I read a source.

We find responses like these heartening and hope to enhance these connections by encouraging students to pursue topics in the CSL course that they are simultaneously learning about in other science courses. We also surmise that if CSL can help science students better contextualize and create connections across traditionally siloed training milestones (e.g., courses in the major) in science, then this may have meaningful implications for students' sense of belonging in their desired fields.

Other students (about 13 of 33) did not see alignments or even saw active tensions between the CSL and other science courses. Interestingly, students did not cite differences in content but rather characterized the tensions as pedagogical or, in a couple cases, epistemological in nature. A couple of students pointed explicitly to grading systems as key factors, as this one did:

> Some frictions in other courses is the grading system. I really enjoyed that this course had a grading contract so I was responsible for my own grade. We were graded on improvement and completion, not right or wrong.

As another student pointed out, the nature of knowledge tends to be of less concern in other science courses, which may have inhibited their ability to draw connections:

> There was more wanting to know about where information came from in this course than others I have taken. Some other professors don't seem to care much about those things.

While the student above noted that the nature of scientific knowing is a matter of value, the student below observes that it is a matter of time and the imperative of content coverage in science courses:

> Science courses don't have the time to teach you the things that this class does. That's understandable, as there is enough to go over in a basic STEM class. Where else am I supposed to learn this except from a more humanities-centered class?

What the variety of responses to this question tells us is that some students are more open to connections between CSL and science courses, in spite of pedagogical and epistemological differences, and some view them as (even justifiably) siloed (i.e., the sciences and the humanities should each stay in their lane). From these findings, we take away an increased motivation to help students bring inquiries from other areas of their studies into our course. A question for future research is to explore the ways science education is structured, pedagogically and institutionally, since those structures likely have direct implications for how students perceive course content. How do high-stakes exams and grade curves, for example, shape students' knowledge frameworks?

Final Thoughts

As the last excerpt above notes, the humanities may have a meaningful role in science education. We continue our efforts to that end through our Critical Science Literacy in the Natural Sciences course, to which students have responded overwhelmingly positively. Demand for the course increases every quarter. But aside from the findings we describe above, it remains unclear how or whether students are bringing CSL forward into their further studies in science. Certainly, we have no evidence that science instructors are aware of the course, let alone aligning their courses with ours.

There are some glimmers of change, however. Just in the few years elapsed between the introduction of this course and the completion of this chapter, there has been a visible shift in the Biology Department's curricular emphases on the situated nature of science and its harmful histories. The department has even begun to assign more writing in its intro series courses (which is no small feat in a course with 700+ students enrolled) and has invited Megan, in her new role as campus-wide Director of Writing, to come speak at the Biology Teaching and Learning Group about teaching writing in science. We view these as promising shifts, though their incrementality reminds us of the many institutional barriers in place to major curricular reform.

For most STEM majors on campus, writing requirements are not "baked in" to the major pathway. Rather, students must "forage" for courses to satisfy those requirements. Some of them do find their way to our course, but even three or four full sections a year serve only a small fraction of the total number of natural sciences majors on our campus. As we have said, the chairs of the natural sciences departments appeared wildly enthusiastic about the CSL course, but none have signaled a commitment to supporting (with funding or labor) a more systematic offering of this curriculum. We aspire to even greater collaboration with and buy-in from science departments that may have the resources to support the broader reach of CSL curriculum. The siloed nature of university disciplines (and department budgets) certainly discourages that kind of transdisciplinary collaboration, but we hope to leverage the growing interest in social justice to foster a stronger exigence for institutional change. Meanwhile, we offer our colleagues the findings in this chapter and in this volume as a testament to the possibilities for inviting rather than suppressing various identities, experiences, and knowledge traditions as a means to belonging in the sciences. After getting a closer look at the sciences, can all students, in fact, see themselves reflected?

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Appendix: Project 1: Tracing the Life of a Scientific Fact

Background

The study of a scientific phenomenon triggers a wide variety of forms of communication, like ripples in a pond. Most published scientific research starts as a peer-reviewed article, but it can get portrayed in a press release, a journalistic article, a social media post, and even make its way into mainstream media like movies or late-night talk shows. The nature of research findings can change, and sometimes get distorted or simplified, as it is translated across communication platforms.

Adjustments in communication are often appropriate according to changing audiences and purposes, such as research reported to a general scientific audience, a more specialized field within science, or to K-12 students or general public audiences. However these adjustments still have an impact on what is understood (or understandable), in what ways, and by whom. (One example of such a cluster of texts is here: https://www.nps.gov/whsa/learn/nature/white-animals.htm). In what ways do these acts of translation affect the actual information?

Assignment Overview

For this project you will select one particular phenomenon and study the "genealogy" of that phenomenon as it moves through various stages of translation: from grant proposal to research article to press release to mainstream media coverage to social media to textbook (to documentary, to literature, to . . .). Not all research articles get translated into other venues, so you will need to find one that has been described in multiple venues. The best way to go about this is to work your way backward: start with some kind of communication in the mainstream media or in social media and trace your way back to the original study.

For this assignment please find a minimum of four different pieces of science communication that all relate to the same research findings. Your sources should have no more than two of the same genre in any analysis (e.g., no more than two tweets, or research articles, etc.). This document gives some pointers on tracing a piece of scientific information across sources (see https://tinyurl.com/3x26a8un).

Assignment Requirements

This project will be composed as a presentation in Adobe Spark, which we got some practice with when we created our own introductions during Week 1 (see https://spark.adobe.com/sp/). I hope you feel some confidence using the platform now, but please do refresh yourself with this tutorial if you need to (see https://tinyurl.com/9y2nsxue). In your Spark presentation you should include the following elements:

- Inclusion of at least four related sources, as described above.
- A written and visual representation of each source. The visual representation is most likely to be a screenshot, though you are welcome to include web links as well. For the textual description, you should consider describing the source in such a way that that the author and context is fully clear, e.g., "Dina Smith is a geneticist at Harvard and she published an article on her research about mice brains entitled 'Mice Brains and DNA…' etc.". You don't need a formal citation in the body of the presentation, though you will need them in the references (see below).
- A central claim or "takeaway" about how or whether the information has shifted across sources (e.g., the information was distorted or simplified; the findings were clearly portrayed and remained faithful to the original claims; the findings became more emotional, etc.).
- Written analysis that amounts to a minimum of about 1200 words. It is perfectly appropriate if chunks of text are broken up by images, external links, or other media. Your analysis should be rhetorical in nature—feel free to attend to forensic, epideictic, and deliberative rhetoric and to the ways that particular vocabulary, titles, images, and tone shift across the translations.
- A list of references at the end of the Spark presentation, properly formatted according to APA format (use the menu on the left for info on formatting different kinds of sources: journal articles, websites, etc.)

Timeline

- Library instruction with biological sciences librarian: Friday, 4/8, 1:30pm
- Rough draft due in Canvas and to peer conference groups: Wed., 4/14, 5pm
- Conference: 4/15 and 4/16 (see Canvas for your assigned time)
- Final draft: Wed., 4/21, 10pm