Linking Labs, Writing, and Information Literacy to Improve Student Success

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Our research and technical writing class develops discipline specific communication and critical thinking skills as a flexible hybrid corequisite to first upper division science laboratory courses. It scaffolds ethics, writing mechanics, information literacy, self-promotion and synthesis assignments focused on the science writing genre (lab notebooks, research papers, posters, grants, online, CVs). Students generate and interpret data from graphs, construct explanations, and practice linking empirical claims to evidence. Instructor, peer and writing tutor feedback is provided on drafts to fulfill California State University's graduate writing assessment requirement. Significant improvement on final research papers following the course interventions was measured.

Keywords: undergraduate, ethics, writing, information literacy

INTRODUCTION

Familiarizing students with primary literature increases students' understanding of the process of science and can change their beliefs about knowledge and learning (Kovarik, 2016; Hoskins, Lopatto, & Stevens, 2011; Hoskins, Stevens, & Nehm, 2007). Researchers have identified activities to teach scientific writing in biology classes, such as metacognition, cognitive instruction, as well as multiple iteration or revision strategies (Dirrigl & Noe, 2019). Linking fundamental scientific concepts to current research creates context and meaningful connections for students (Willard & Brasier, 2014). Competent scientific writing requires that students use not only proper grammar and the mechanics of writing, but also argumentation and rhetoric (Colabroy, 2011). Moreover, equipping students to converse with the reader and connect with the science requires critical writing and quantitative reasoning (Otfinowski and Silva-Opps, 2015). The critical analysis necessary to write scientific literature includes constructing claims, providing supporting evidence, and arguing from evidence using inference and reason. The course includes both Writing-to-learn (WTL) tasks to increase biology students' competency as well as writing-to-communicate (WTC) tasks with an emphasis on synthesis and clarity (Balgopal et al., 2018).

Instructors facilitate students' full understanding of the issue or problem by defining key terms, exploring ambiguities, determining boundaries, and ways to connect all relevant information. To cultivate information literacy and appropriate sourcing, instructors provide feedback as students organize, interpret, analyze, and synthesize information from sources to fully achieve a specific, intended purpose with clarity and depth. Increasing students' awareness of the complexity of correct paraphrasing and citation rules can occur through focused in instruction and activities revealing student misconceptions about paraphrasing and citations (Zwick et al., 2019). Students in this class are tasked with creating primary written work using an iterative process requiring practice with revision(s) based on feedback from the instructor, peers, and the broader community via Wikipedia and the campus cooperative learning center (CLC). They are taught strategies to integrate word choice, improve structure, and use strategic transitions to convey knowledge and meaning, and to only convey relevant content.

Undergraduate students have limited access to undergraduate research, apprenticeships, and internships in large enrollment public universities. It is possible that students who are given the opportunity to engage in undergraduate research will report greater gains in learning (Bickford, et al., 2020). Meaningful research experience and scientific inquiry exposure lead to higher likelihood of persistence in the major (Cattone et al., 2020) and continuation in science careers after graduation (Laursen, 2019; Armbruster et al., 2009). To address this inequity, we are developing course-based undergraduate research experiences (CUREs). Most laboratory sections in the department are working toward the development of CURE content. Students work individually, or in groups, and even as a class research team to collect data based on real world applications. The CUREs are generating large amounts of data that is generally lost at the end of the semester due to the lack of time in the research skills-based classes to thoughtfully analyze and synthesize results.

This study aims to identify the results of pairing a writing intensive class with the first upper division laboratory course to improve student success by teaching these critical thinking skills in context. Communicating an idea clearly and effectively allows scientists to share ideas with policy makers, fellow researchers, or society (Cirino et al., 2017). Scientific writing incorporates logic thinking and a specific structure of argumentation: claim, evidence, and reasoning (MacNeill & Martin, 2008). Engaging writing utilizes grammar and writing mechanics to convey context, new information, and next steps. This course teaches students as scientists to become more effective writers (Verkade & Lim, 2016). The instructors use practical examples and writing for a purpose, ultimately producing a scientific research paper. Topics students encounter include principles of good writing, the format of a scientific manuscript, peer review, grant writing, ethical issues in scientific publication, and writing for general audiences. The ultimate goal is to develop the scientific identities of our students and reduce the feelings of imposter syndrome (Marx et al., 2019). If we can help our students see themselves as scientists and be comfortable in this role, we can increase the number of Under-represented Minority (URM) and First Generation (FG) students who choose a career in science (Segarra et al., 2020).

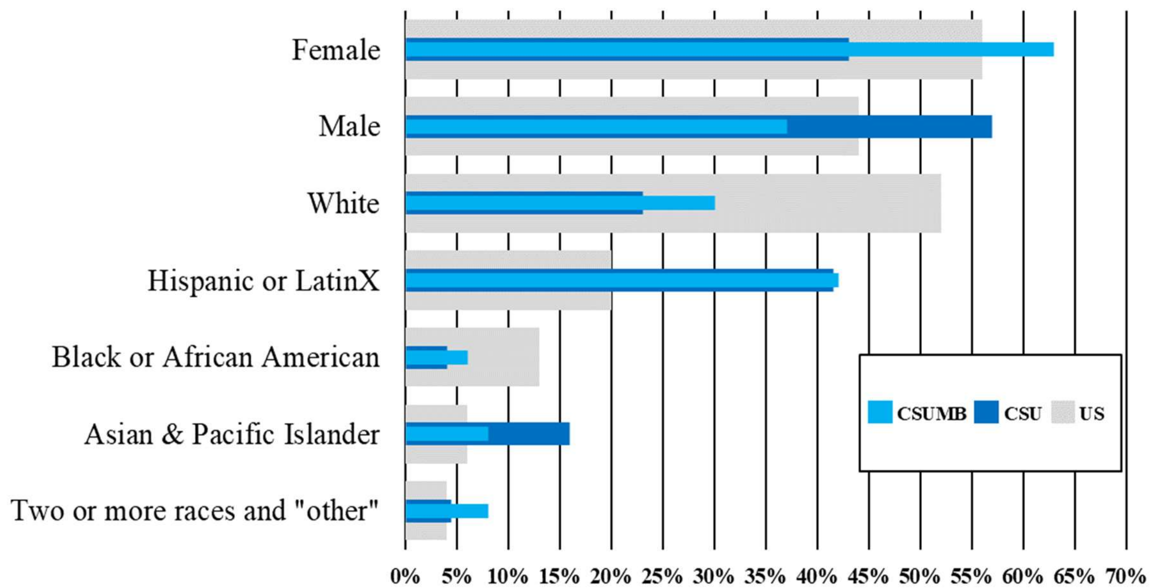
The addition of two units of the California State University system-wide Graduate Writing Assessment Requirement (GWAR) Scientific Writing as a supplement to one of these junior level upper division courses laboratory supported courses offers the ideal learning incubator for the development of ethics, communication, and critical thinking skills in the discipline. Students are advised to take the two-unit GWAR addition during the semester in which they are first enrolled in any of the junior level upper division courses that can serve as the co-requisite. These sections offer additional non-laboratory, and non-content-based instruction specifically related to ethics, writing mechanics, information literacy, synthesis and self-promotion.

METHODS

Faculty designed a series of assignments for use in a co-requisite writing course paired with upper division undergraduate research methods courses. Designed to develop information literacy, critical thinking, and integration skills, faculty scaffolded a series of assignments to build competency with support to develop student writing skills. The assessments accompany active learning including exercises in which students write, discuss, solve, or reflect (Couch et al., 2015). Formative assessments occurred during the exercises, while summative assessments captured students' knowledge and skills at the end of the course, in this case a final research paper. The achievement of course learning objectives were measured initially with formative assessments and cumulatively through the summative assessment. Students communicate scientific results after synthesizing data and drawing conclusions based on evidence and reasoning.

The participants in this study were 98 undergraduate students enrolled in upper division microbiology (66, BIO 320) and Evolution Biology and Population Genetics (32, BIO 341) during the 2019 fall semester. The study was conducted with approval from the institutional review board. The population was 70% Female and 30% Male. There were 98 students enrolled in 5 lab sessions: 66 in Microbiology and 33 in Population Genetics. The demographics of our student sample show diversity: Hispanic/Latino(a) students (43%), Black (5%), Asian (10%), Pacific Islander (2%) and Native American (1%). The demographics of our student sample were 70% Female and 30% Male. Comparative demographics of a medium size public institution (7600 students), the California State University system (481,929 students), and across the United States (16.6 million students) are shown in Figure 1.

FIGURE 1
DEMOGRAPHIC DATA FROM CSUMB, THE CSU SYSTEM (CSU), AND UNITED STATES (US)



Summative assessment strategies do not always capture the open-ended, collaborative, cross-disciplinary, iterative, and dynamic nature of laboratory research, project-centered learning, or CUREs. Embedded assessment directly weaves assessment into the learning environment and authentic activities, such as writing research papers as a scientist, so student learning can be monitored and supported in real-time without interrupting the flow of learning (Shute, Ventura, Bauer, & Zapata-Rivera, 2009). Embedded assessment has been widely adopted in digital learning environments to design tasks that elicit evidence of desired outcomes, and to automatically and rapidly capture and process rich data generated in the process of performance (Wilson & Sloane, 2000). Our goal was to embed assessments throughout the scaffolded writing assignments to provide iterative feedback. To minimize workload and model the on-line evidence we developed this course in a hybrid format so that some of the student work did not require direct faculty feedback.

We analyzed student writing from three subgroups with: 21 students from Microbiology with No Iterative Feedback; 18 from Microbiology with Iterative Feedback**; 12 in Population Genetics with Iterative Feedback** Assessed 2 writing assignments using a variation of the AAC&U Written Communication Value Rubric (Rhodes, 2010). We collected two writing assignments from Fall 2019 per course, one was within the first three weeks of class, the other was the final research paper. Identifying information was replaced with a random ten-digit number. 60 randomized samples of the work of 10 students per section were evaluated using a rubric: one Evolution Biology and Population Genetics and two Microbiology courses. One of the Microbiology sections had students with less of a connection to the writing class in that students wrote a literature review rather than generating their own primary work based on the data collected in the research methods class.

Student work was evaluated using a variation of the written communication Value Rubric developed by the American Association of Colleges and Universities (AAC&U) (Rhodes, 2010; Rhodes & Finley, 2013). The VALUE rubrics were developed through collaborative efforts of teams of faculty experts representing colleges and universities across the United States. By examining many existing campus rubrics and related documents for each learning outcome and incorporating additional feedback from faculty, the rubrics articulate fundamental criteria for each learning outcome, with performance descriptors demonstrating a progression of achievement. Two critical criteria were identified by faculty as priorities for improving student writing: 1) explanation of the issue and 2) use of support. The constructed responses and final reports were anonymized and scored blindly by three evaluators who first normed several samples following a norming and calibration protocol according to (Suskie, 2018).

Inter-rater reliability was determined through a count of ratings receiving the same scores divided by the total number of ratings completed. This measure of inter-rater reliability has been shown to be the most commonly applied when calculated to exact or adjacent agreement (Jonsson and Svingby, 2007). The target for agreement is 100%, but Stemler's (2004) guidance that agreement between raters should reach at least 70% has been adopted.

COURSE DESCRIPTION

In biology at CSUMB, as with most natural sciences, all students are required to complete several junior level courses that have both content and laboratory aspects to them (e.g. Ecology; Evolutionary Biology and Population Genetics; Microbiology; Plant Pathology). While we developed this course for the biological sciences, it could be used for any courses with an applied aspect that produces novel information or materials such as the chemical or physical sciences, psychology, social sciences, or the arts. In our department these biology courses are typically offered for four units in which the content is delivered in two units of seminar and one unit of laboratory and one unit of discussion. The seminar is usually associated with a K factor of 01 (Large Lecture) and meets three hours per week. The laboratory sections offer applied and enriching learning experiences in a setting more like that of a 'real' scientist as compared to the lecture.

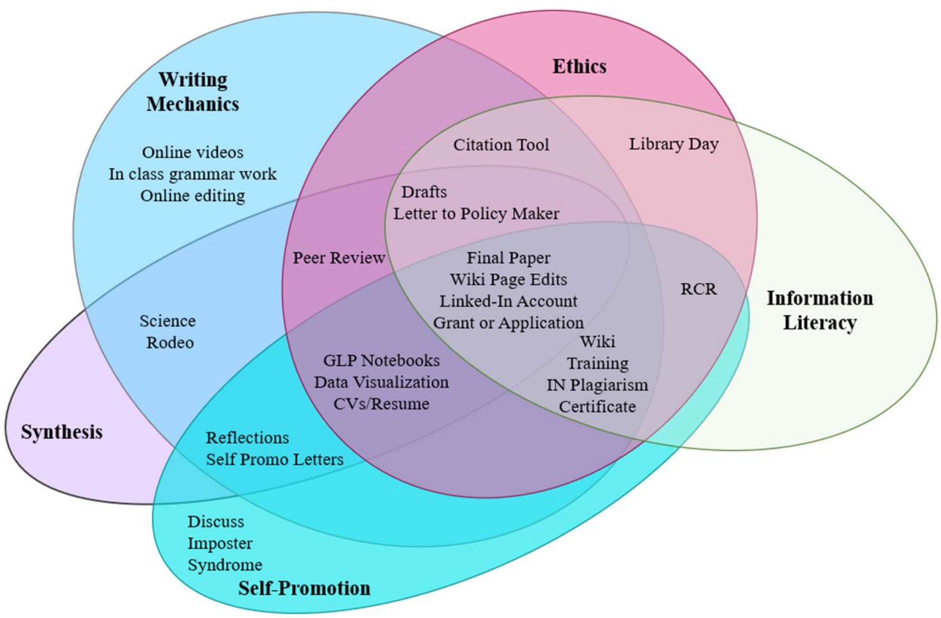
Students meet for three hours for the additional two units, and faculty are given two units of workload. The components of a CURE course, collaboration, iteration, discovery, implementation of scientific practices, and broad relevance, were achieved through classroom support and co-instructor research mentorship (Auchincloss et al., 2014; Brownell & Kloser, 2015). We focus here primarily on the development of five components of being a good science communicator: ethics, writing mechanics, information literacy, synthesis and self-promotion. All five categories of these meta-skills to support the CURE were developed during the semester in the GWAR course (Table 1). A table of the meta-skills (Table 1) will not accurately represent the integrated relationships between each of the groups. When communicating with students, we endeavor to show the overlap in an Euler Venn diagram Figure 2.

TABLE 1
GWAR COURSE COMPONENTS, ASSIGNMENTS, AND ASSESSMENT METHODS BY CATEGORY

Course Component	Writing Assignment	Assessment Methods
Ethical Foundations		
Plagiarism Responsible Conduct of Research (RCR) Science Practices; Standard Operating Procedures, Safe Lab Environment	University of Indiana Plagiarism Certification CITI Training in RCR Good Lab Practice/Notebooks	Empirical Claims on Written Work Needed Proper Sourcing & Support Summary RCR Quick Write Pre and Post RCR reflection *Evaluated in Corequisite Lab Course
Information Literacy		
Proper citation of sources Searching Literature and obtaining quality sources; Citing Sources on Wikipedia Sourcing Lab Reports Sources for Letters to Policy makers	Instruction in citation tool (e.g. Mendeley or Zotero) Librarian Searching & Citing Class Day Wiki University Lab Report Supporting Evidence Letter to Policy Maker	Information Literacy Rubric Attendance-based Peer review, Wiki staff evaluates for appropriate sourcing Peer review, Instructor Feedback and CLC Instructor feedback and ideally response from policy maker
Synthesis		
Development of Quantitative Reasoning Skills Instruction on Graphing and Statistics	Lab Report Drafts and Final Results and Discussion Adding content to Wikipedia Science Rodeo, Lab Report Results	Peer review, Instructor Feedback and CLC Integrative Knowledge Rubric Quantitative Reasoning
Writing Mechanics		
Online Videos (based on Stanford Med. School Coursera Course with Permission) In-Class grammar activities Posters Website Editing 3 Drafts and Final Copy of GWAR	Grammar, Punctuation, Verb Tense, Active vs. Passive Voice, Cutting Clutter Writing mechanics; Science Rodeo Wikipedia Electronic Peer Review of Final GWAR papers	Google Doc submission graded for completion Written Communication Rubric Reviewed in class on the whiteboard, or in breakout groups, but graded like an exit ticket (Marzano, 2012; Danley et al., 2016) Class voting on best in show In class presentations of website edits Instructor gives final assessment based on CSU GWAR guidelines

Self-Promotion		
Recognition that professional development is not static Modeling the construction of a CV or Resume Future planning & Self-Assessment Instruction in permanence/ stasis and constant evolution of online presence	Discussions of Imposter Syndrome (Kolligian et al, 1991; Bravata et al, 2019) Resumes or CVs with drafts early and late in the semester One page grant proposal or scholarship application or application to future career goals Draft Letter of Support for selves LinkedIn Accounts/Networking	First draft for feedback (credit/no credit), second on improvement and inclusion of items known to have been covered in this course and the CURE Mechanics and clarity, and the ability to follow the instructions Positive feedback and suggestions for inclusion of missing items only Did they join the department network, and in a professional manner?

FIGURE 2
EULER VENN DIAGRAM OF COURSE COMPONENTS



During the course students received training in the responsible conduct of research. Students completed the CITI Responsible Conduct of Research (RCR). The National Institutes of Health (NIH), National Science Foundation (NSF), and U.S. Department of Agriculture (USDA) require researchers to certify they have received RCR training. This course provided an in-depth review of the core RCR topics including authorship, collaborative research, conflicts of interest, human subjects, and research misconduct. Students explored case studies and video examples. Through the RCR training students learned to attribute information to sources, as well as paraphrase, summarize, or quote in order to use information in ways that are true to the original context. Part of the RCR training also helped students to distinguish between common knowledge and ideas requiring attribution. Students' knowledge of ethics with regard to plagiarism were assessed through multiple measures including the University of Indiana's "How to Recognize Plagiarism" certificate as well as the mandatory online instruction from Wikipedia prior to being allowed to edit any content. Students were also assessed on their implementation of good laboratory practice, including keeping of written records in a laboratory, recording and implementing standard operating procedures, and maintaining a safe laboratory environment.

Information literacy in this course included searches, literature reviews, careful reading of abstracts, and annotating bibliographies. Course activities encompassed the discovery of information, the understanding of how information is produced, articulating the value of information, and the use of information in creating new knowledge. Students spent a class period with a librarian. Students learned to select a variety of information sources and to evaluate their quality in context of the discipline. Students practiced sorting sources after considering the importance of multiple criteria, such as relevance to the topic, currency, authority, audience, and bias or point of view. Students learned to use citation resources such as Mendeley or Zotero. In addition to attributing information to the creator of that information, students learned to provide authority and context for the audience. Their citations made it possible for their peers to find and/or replicate their research. Students in CUREs that found novel microbes, for example, learned the frustration of the limited sources on some topics.

The writing mechanics components of the course included asynchronous online videos and synchronous in class grammar activities. The asynchronous online videos included content from Dr. Kristin Sainani's Writing in the Sciences course. In addition, Dr. Alison Haupt created additional video content specifically addressing writing in the genre. Students created and edited Wikipedia pages. Students wrote to different audiences including outreach to non-scientific audiences such as policy makers or in blogs, writing for a general science audience through research papers, and writing for a specific field or discipline through proposals. Through active learning strategies students organize, interpret, analyze, and synthesize information from sources to make sense of information. Students use evidence and scientific reasoning to articulate a conclusion with clarity and depth. Students participated in Science Rodeo, where they craft a compelling storyline to make sense of data in a figure.

Students generated three drafts prior to their final research paper submission. Each draft was reviewed, and peer edited as well as receiving instructor feedback. The goal of engaging students in peer reviews of scientific research papers is to prompt students to carefully read each other's work with an eye to the criteria used by experts in the field to assess the quality of the work. In using rubrics for formative exercises, instructors may increase students' awareness of the general and discrete criteria that scholars seek in academic papers, and increase students' sensitivity to the standards of performance, so that they may be better able to distinguish subtle but important differences between achievement that is accomplished and achievement that is exemplary, and achievement that is accomplished and emerging or nascent. The objective of formative assessment was also to provide students with insights as to the strengths and limitations of their work prior to the submission of that work for a summative grade.

An additional benefit of the course was coaching the development of the scientific identity of our students, and suggestions on ways that they can present themselves digitally, and via a resume or curriculum vitae. As the semester progressed, we updated their achievements in real time to show them ways that what they were learning (e.g. a Plagiarism Certification from the University of Indiana, or the ability to edit Wikipedia) were relevant to their future professional goals.

RESULTS

Comparing three courses, two with interventions and a control without, we identified the following patterns in the data. Consistently, on the first draft for explanation of issues and use of support, 80% of students scored below proficient. By the fourth and final draft, 80% of students who had interventions scored proficient or above in both categories. For the control, which received no intervention, only 20% of students scored proficient or above at either time point. As shown in Figure 3, students improved significantly between the early and later drafts in their statement of the Clear Issue/Problem. As shown in Figure 4, students improved significantly between the early and later drafts in their uses of support. The students who had interventions are marked with a double asterisk (**).

FIGURE 3
STUDENTS STATED CLEAR ISSUE/PROBLEM

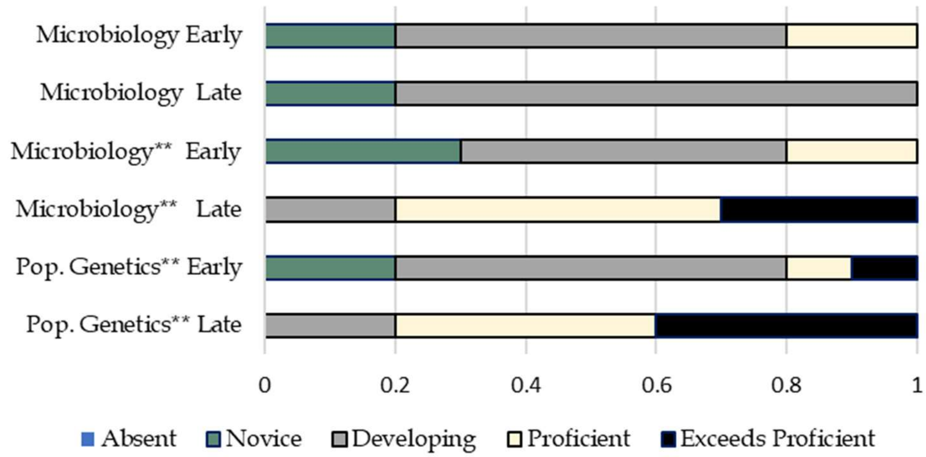
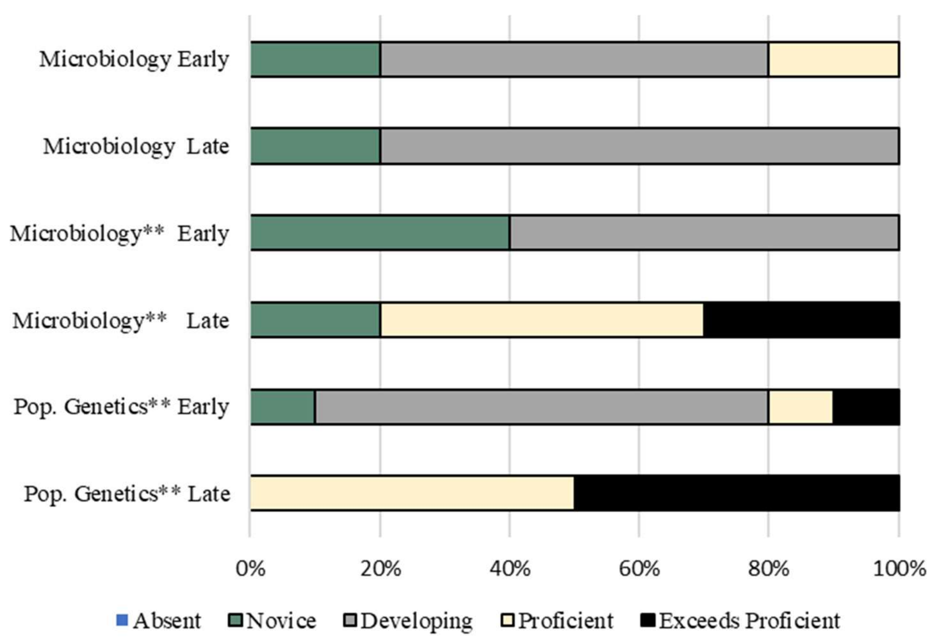


FIGURE 4
STUDENTS USED SUPPORT OF CLAIMS



DISCUSSION

We have found that pairing a writing intensive class with the first upper division laboratory course was able to improve student success by teaching critical thinking skills in context. The students with iterative intervention in ethics, writing mechanics, information literacy, synthesis and self-promotion improved significantly. The students with no iterative intervention remained below proficient or developing in their writing skills throughout the semester. Undergraduate research opportunities frequently incorporate science communication as core components of the curriculum (Lopatto et al., 2013; Sarmah et al., 2016). Writing in this course was not ancillary to the research experience, but an integral component. Authentic research experiences confer benefits to students including professional skills, thinking and working like a scientist, confidence in research skills, and an increased interest in a STEM career (Seymour et al., 2004; Russell et al., 2007; Handelsman and Brown, 2016). As a Hispanic Serving Institution CSUMB has many students who are first generation college students (53%) and underrepresented minorities (51%). (CSUMB IAR) making these interventions ideally suited to promote students beyond graduation. CSUMB was recently ranked 5th on top performers on social mobility (US News and WR 2020). We observed students who were able to self-promote using curriculum vitae reflecting their development as scientists, integrating their professional skills, thinking and working like a scientist into their next steps on a career path.

Practice in scientific communication provides students with the opportunity to convey the broader context of the work in which they participated (Coil et al., 2010). Through the Science Rodeo as well as the formal, final draft of their research paper, students were able to use critical thinking and quantitative reasoning to present their findings. Science communication enhances student research experiences (Mulder, 2008; Chan, 2011). Cirino and colleagues implemented a course focused on elevating science oral communication skills in advanced undergraduates (2017); Our efforts to develop an undergraduate writing course complementing upper division research methods courses provide students with experiences to communicate as scientists. The authors would be happy to share any of our course materials upon request.

CONCLUSION

Critical thinking, collaboration, and communication skills are among the top skills that employers are looking for in job candidates (NACE, 2020). By participating in the course, students encountered multiple opportunities to develop their communication skills, hone their writing mechanics, and integrate information literacy and ethics into their research experience. These skills complement the synthesis students engage in to make sense of the science, interpret data, and argue from evidence.

Incorporating a series of writing experiences similar to Dirrigl and Noe (2019), the co-requisite writing course described in this paper included: 1) understanding the role of student metacognition, cognitive instruction, and strategic teaching, 2) recognition of different student writing levels, 3) applying the writing process, 4) demonstrational classroom revision and editing, 5) student-teacher sentence editing, 6) student peer editing and guided student editing, 7) student copy-editing, 8) reflective writing, 9) addressing plagiarism, paraphrasing, and proper in-text citations and referencing, and 10) using external, on campus and online resources. However, each of these components were specified in the syllabus and instructor driven. In order to develop student agency, future research efforts include the evaluation of a grant proposal developed by students and driven by their interests. As a self-initiated assignment, this writing prompt has minimal instructions and requirements. Instead, students must identify the components of their own writing process and produce a final product through that process. This enables students to choose to incorporate components such as peer editing and the instructors to evaluate student competency. Student work will be scored using the same value rubrics (Rhodes, 2010) with an emphasis on providing feedback similar to a review panel for external funding agencies such as the National Science Foundation and the National Institutes of Health, positioning students as scientists, receiving feedback from a community of their peers.

ACKNOWLEDGMENTS

Alison Haupt (writing modules); Eric Crandall (BIO341 course design), Cooperative Learning Center (CLC) Tutors (Nanda Warren); Stanford Medical School Writing Program (Kristin Sainani); Communication Across the Disciplines (Nelson Graff).

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