Writing Matters: Increasing Undergraduate Cell Biology Literacy through Writing-to-Learn Activities

Meena M. Balgopal, Colorado State University
Anne Marie A. Casper, Colorado State University
Paul J. Laybourn, Colorado State University
Ellen Brisch, Minnesota State University Moorhead
Alison M. Wallace, Minnesota State University Moorhead
Steven Dahlberg, White Earth Tribal Community College

Biology educators need instructional strategies to improve student learning and achievement, especially in foundational courses when students are presented with vast amounts of content knowledge. Writing-to-learn (WTL) tasks in lecture courses can help biology students improve the quality of their arguments and increase content knowledge. WTL activities can model how scientists use inductive reasoning to design studies and arguments; encourage revision of ideas; support peer review and discussion; and help with writing-to-communicate tasks. Our WTL interventions include the use of graphic organizers, iterative writing, peer evaluation, and self-evaluation. We examined the effects of WTL on content knowledge, performance (grades), and argumentation. WTL is associated with 1) increased use of abstract concepts over the course of the semester in two WTL interventions (intense and moderate); 2) increased performance for some students (first generation, women, and minorities); and dialectical argumentation (persuasive) compared to demonstration arguments (expository).

Introduction

Writing allows people to organize their thoughts and make meaning of new content,[1] necessary precursors for preparing written arguments.[2] Organizational or reflective writing is collectively called writing-to-learn (WTL). Common outcomes of WTL activities include increased awareness of one's own learning and knowledge (metacognition), integration of new knowledge with prior knowledge, organization of knowledge from concrete to abstract conceptions, and plans for communicating concepts with others. Although writing has been integrated into many undergraduate biology courses, most instructors focus on writing-to-communicate (WTC) outcomes, rather than on WTL processes.[3] WTC may be framed as narrative, expository, or persuasive texts, yet instructors are not always explicit with students about the types of planning needed for these tasks. Some science instructors feel that the integration of writing should be reserved for English composition courses or is too time-consuming to assess.[4] Biology educators tend to focus on outcome tasks (written papers or reports) and offer guidance through individual feedback, rubrics, or peer review rather than helping students organize their thoughts before a draft is constructed. WTL studies in undergraduate biology courses can inform eductors on how to help students learn content.

Experts in science literacy and learning argue that it is through the practice of using language that science students are able to reflect on their prior knowledge, connect language to abstract concepts, and adopt discursive practices of scientists.[5,6,7] Wallace proposed a theoretical framework to study scientific literacy and scientific language use.[5] She described three constructs of this framework: *Third Space*, *Authenticity*, and *Multiple Discourses*. The Third Space subconstruct recognizes that speakers/writers

make meaning by drawing on both personal (first space) and scientific (second space) ways of knowing the natural world. Wallace explained that the discursive movement between vernacular and scientific discourse only occurs when learners have a reason or a context in which to express themselves and their ideas differently, defined by *Authenticity*.[5] The *Multiple Discourse* subconstruct acknowledges that all individuals engage in different types of communication depending on the context, content, and levels of confidence and familiarity with the topic. Learners move from self-talk (private) to authoritative (public) discourse and adopt different *voices* in their writing/speaking that reflects their levels of literacy. These three subconstructs informed our research on the design, implementation, and evaluation of science literacy.

We are interested in how undergraduate students express their conceptions about cell biology while developing persuasive arguments about which cancer treatment they would recommend. As students developed their arguments in WTL texts, we analyzed how they wrote about cancer and how they described cell parts (e.g., organelles), processes (e.g., glycolysis), and forces driving these processes (e.g., diffusion or ATP generation), in addition to their description of the biological and emotional trade-offs of various treatments that they learned about through *Science News* and *New York Times* readings assignments, textbook reading assignments, and lecture notes.[8] Our exploratory study examined various WTL interventions (iterative writing, graphic organizers, peer evaluation, and self-evaluation) on how students expressed their content knowledge. Our goals are to identify what types of interventions are associated with increased knowledge (especially use of abstract concepts in written arguments), performance gains, and dialectical (persuasive) writing.[6,9]

Methods & Findings

Our interdisciplinary team, comprised of biology and science education experts, tested our WTL model at two universities and one tribal college. Colorado State University (CSU) is a Ph.D. granting university where biochemistry majors take a foundational cell biology course as first semester sophomores; 150-200 students enroll each year and may enroll in an optional laboratory section. The instructor (PJL) has taught this course for the past 15 years. Minnesota State University Moorhead (MSUM) is primarily an undergraduate university where biology majors are expected to take a foundational cell biology course as second semester freshmen and coenroll in a required laboratory course. The instructor (EB) has taught this course for the past 8 years. At both institutions White students and those from college-educated families outnumber minority and first generation students, and women slightly outnumber men. White Earth Tribal Community College (WETCC) is located on the White Earth Reservation, near MSUM. MSUM and WETCC science instructors have been collaborating on WTL projects for the past 9 years. Almost all WETCC students identify as Native American (as Anishinaabeg). WETCC students enrolled in either a speech or biology course, both centered on persuasive communication, were recruited and asked to select one of three locally-relevant health issues: cancer, Type II diabetes, or alcohol addiction. All CSU and MSUM students wrote exclusively about cancer biology. Written work only from consenting students at all three institutions were analyzed; although, all students enrolled in the selected courses were expected to participate in WTL activities. To

date,1,095 students have participated in our study.

We designed four WTL conditions: A) no writing (control), B) lots of writing (3 essays with weekly WTL assignments over 15-week semester), C) some writing (3 essays-one every five weeks without WTL assignments), and D) little writing (1 essay in week 15 without WTL assignments). Students in Condition B read general science articles about cancer treatment and were asked to regularly consult their class notes and textbook. They then were asked to choose graphic organizers (GO) to organize their thoughts over three weeks on what they knew; felt (connection/reaction to prompt); and would do (select cancer treatment). We provided example GOs from Microsoft ® Word's (v.15.15) SmartArt library. We also provided examples of how GOs could be used to organize thoughts but for a different biological topic (fertilizer use in agriculture and hypoxic waters).[10] In week 4, students engaged in peer review to identify strengths and areas for improvement. In week 5 students submitted revised essays, indicating how they used peer feedback, and self evaluation (highlighting "big ideas/claims," bolding "reactions or personal connections to cancer" and underlining "tensions to resolve"). Condition C students submitted self-evaluated essays every five weeks, whereas condition D students submitted only one self-evaluated essay in week 15. Students at CSU and MSUM took a cell biology concept inventory as a pre and post test in all conditions (A, B, C, and D). Our research design enabled us to ask six research questions (Table 1).

Table 1. To determine how writing-to-learn (WTL) interventions in foundational cell biology courses affects content knowledge, performance, and written argumentation skills, six research questions were asked.

Research Question	Data	Analysis
1. How do WTL interventions affect performance?	• Final course grades (without WTL grades) • Final course grades (including WTL grades) • Pre and post concept inventory test scores (Conditions A, B, C, D)	Mann-Whitney U, Shapiro-Wilk test for normality to determine non-parametric statistics were warranted (using SAS v. 9.3)
2. How do students' use of content terms (parts, processes, forces) differ among interventions?	Final essays • 3 for Condition B (with WTL) • 3 for Condition C (no WTL) • 1 for Condition D (no WTL)	Content analysis[11] (NVIVO) Semantic analysis (to ensure valid use of terms) Pearson's Chi square test
3. How does peer evaluation given synchronously (during labs) or asynchronously (online) affect the types of feedback given and how do students revise their writing?	• Feedback given by each student to two peers • Feedback received by each student from two peers • Self-evaluation (Conditions B and C) • Final essays (Condition B)	Thematic analysis[12]
4. What is the relationship between use of different graphic organizers (GOs) and performance and knowledge gains?	Graphic organizers Final essays (Condition B) Essay grades Final course grades	Thematic analysis[12] Content analysis[11] Spearman Rho test ANOVA
5. What is the relationsip of level of WTL intervention and quality of argumentation?	Final essays for • Condition B (WTL) • Condition C (no WTL) • Condition D (no WTL)	Rhetorical analysis[6,9]
6. How does health topic	• Graphic organizers/ student work	Thematic analysis[12]

(cancer, diabetes, alcohol addiction) affect the quality and framing of tribal college students' writing?	• Power Point presentations • Final essays • Focus group interviews (recorded and transcribed)	Rhetorical analysis[13]

Chi square tests run on students in control sections (A1, A2, A3) and intervention conditions (B, C, D), indicate that there were no significant differences among the classes based on grades earned in a prerequisite foundational biology course. Hence, we are able to compare the effect of WTL interventions across conditions. All students (Conditions A, B, C, D) scored significantly higher on posttests than on pretests; however, gains on the concept inventory were not significantly higher in any one condition. Hence, WTL was not detrimental. Student grades were not normally distributed, according to a Shapiro-Wilk test for normality; therefore, non-parametric Mann-Whitney U tests were run. A comparison of the final exam scores across conditions at CSU demonstrate that of the students who completed most (75%) of the WTL assignments (n=66), minority students in Condition B (n=13, median=84) significantly outperformed their counterparts in Condition D (n=24, median=71.5; z=1.78, one-tailed p=.0375). Likewise, first generation students in Condition B (n=19, median=77) significantly outperformed their counterparts in Condition D (n=31, median=72.6; z=1.77, one-tailed p=.0376). Women performed equally well in treatments B and D, but performed better in all writing treatments than in all control treatments when compared to their male counterparts (all comparisons, one-tailed $p<.05$).

Students in Conditions B and C (at CSU) used significantly more abstract concepts over the semester. For example, by the final essay Condition B students (n=66) wrote more often about forces and processes than in the first essay (X^2, n=9845 words) = 956.63, $p<.0001$. WTL significantly predicts final grades for both students with complete writing assignments and for those who had incomplete sets (n =116; $p<.0001$).

Students identified strengths and areas for improvement in at least two of their peers' WTL drafts. Peer review comments fell into 25 categories, which, after multiple rounds of inductive coding, were collapsed into 3 rhetorical codes: *ethos* (credibility), *pathos* (use of appeals), and *logos* (logic/ reasoning). Peer review centered on: 1) writing mechanics and 2) content knowledge (affecting the author's ethos), and 3) quality of argument (establishing pathos and logos). Other peer evaluation analyses are ongoing.

Students used 24 types of GO's, which were classified, through inductive coding by five researchers, into 5 overarching GO types. The majority of students at both CSU (85%) and MSUM (78%) used the same category of GO throughout the semester for each WTL assignment. GOs or essays alone do not predict grades, so the combination of GOs and essays is important. Only the second ($\rho=0.3772$, $p=0.0005$) and third sets ($\rho=0.3480$, $p=.0024$) of GOs are correlated with respective essays at MSUM (n=81), so there appears to be a learning curve.

The rhetorical (argumentation) and framing (WETCC) studies are still in progress. Preliminary analyses of argumentation of 18 randomly-selected, Condition blinded essays from students in Conditions B and C indicate that 89% of Condition B essays

were *dialectical* arguments for which persuasive reasoning is required (e.g. “you need to weigh the pros and cons of each treatment”). In contrast, 100% essays from Condition C were *demonstration* arguments for which only commonly accepted premises were presented to support conclusions (e.g. “I would accept the cancer treatment recommendation”). The Aristotelian distinction of *dialectical* (persuasive) and *demonstration* (explanatory) was useful because although we did not provide instruction on these two genres of arguments, we were interested in patterns that might emerge in the two instructional conditions. Two coders agreed on the classifications. In our first year study at WETCC students (n=24) self-selected evenly into each of the three health issues. Initial analysis of focus group interviews revealed that almost all of the students framed their speeches around personal connections, and half of the students dichotomized Western and Native ways of knowing about health. In our second year study at WETCC we are finding that students (n=13) have been able to draw on academic science knowledge mid-semester after many explicit class discussions about different “ways of knowing:” Native/traditional versus Western science/academic.

Discussion & Implications

WTL activities benefit undergraduate students studying cell biology based on several measures. Because of limitations of concept inventories, the findings from other measures of content gain and performance may be more informative.[15] The most important finding is that weekly WTL interventions benefited underrepresented students’ (first generation and minorities) performance (exam and course grades). Women students’ performance also increased in WTL Conditions. It appears that regular WTL (Condition B) encourages students to revisit content as well as organize new concepts learned through lectures and readings. The iterative nature of the assignments enabled students to revise their organization (demonstrated by the use of various GOs), presumably promoting metacognition.[1,16] Criticisms of GO research include the fact that these tools are used to promote memorization, study only one GO at a time, or that assessment is conducted immediately after GO use.[17] However, by integrating GOs as part of the iterative writing interventions, as suggested by our Advisory Board (three English department faculty members with expertise in writing across the curriculum), the current project avoids these pitfalls. It is important for instructors to help students recognize that there are different types of arguments (expository and persuasive); and the initial findings of the rhetorical argumentation study indicate that sustained WTL interventions enable students to examine content in deeper ways so they can construct dialectical arguments, which is how scientists communicate with one another.[2]

In summary, WTL interventions can be powerful and meaningful to undergraduate biology students. They can improve use of abstract concepts in writing, performance, and argumentation skills. To date, our team has lead 11 presentations (6 workshops and 5 seminars) and will be leading a NARST-sponsored presentation at the National Science Teacher Association conference in spring 2016. Seven colleagues have begun integrating WTL in their courses across four institutions. We have disseminated our WTL interventions through a website[10] in addition to preparing six manuscripts (for each research question) for submission to journals.

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Biographical Information

Meena Balgopal is an Associate Professor in the Department of Biology, CSU. She has a PhD in Zoology and has been studying the effect of pedagogical innovations (problem-based learning and writing-to-learn) in undergraduate biology and engineering courses since 2003. Paul Laybourn is a Professor in Biochemistry & Molecular Biology, CSU. His research has shifted from studying mitochondria to exploring pedagogical strategies to help diverse students succeed in life science courses. He has been directing an NSF REU program for the past 12 years. Alison Wallace is a Professor in Biosciences, MSUM, who is trained as a plant ecologist. She studies and teaches science pedagogy and is the outgoing director of the MSUM Faculty Development Center. Ellen Brisch is a Professor in Biosciences and is the former department chair. She engages undergraduates in research on yeast cell division and cell movement. Steve Dahlberg has a PhD in Metereology and has been the Science Program Head at WETCC since 2002. Anne Marie A. Casper is a doctoral candidate in ecology and ecology education at CSU studying how undergraduates learn, write, and engage in group discourse in various science courses in the Balgopal lab. The current grant (TUES # 1244889) is an extension of a previous DUE grant (CCLI # 0930978) awarded to Balgopal, Wallace, and Dahlberg to study WTL ecology in small class settings.