FEATURE ARTICLE

Writing-to-Learn, Writing-to-Communicate, & Scientific Literacy

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Abstract

Writing-to-learn (WTL) is an effective instructional and learning strategy that centers on the process of organizing and articulating ideas, as opposed to writing-to-communicate, which centers on the finished written product. We describe a WTL model that we have developed and tested with various student groups over several years. With effective instructor guidance (through prompts and in-class discussion), students demonstrated greater scientific literacy after participating in writing activities about engaging socio-scientific issues. We believe that WTL activities are underused in secondary and post-secondary biology courses.

Key words: *Scientific literacy; writing-to-learn; undergraduate; secondary science; socio-scientific issue.*

It is essential that science educators guide their students to think about socially important biological issues, such as reproductive technologies, food production, and climate change, which are just some of the issues that dominate news stories. To prepare students to understand such issues and make informed decisions about how to resolve these problems, science educators must find instructional strategies that guide students to make sense of biological concepts and interpret scientific evidence within societal and personal contexts. In doing so, students will increase their level of scientific literacy. Here, we describe our experiences using a writing-to-learn model designed to encourage the development of scientific literacy in secondary and post-secondary science students.

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○ Scientific Literacy

A scientifically literate student must be able to communicate his or her ideas through writing or speaking, demonstrating the most essential skills of science literacy (Norris & Phillips, 2003; Krajcik & Sutherland, 2010). In addition, science students must have sufficient background content knowledge in order to explore specific types of scientific issues in depth. For example, an ecologically literate individual would be able to articulate that (1) environmental systems are complex (Jordan et al., 2009); (2) humans are a part of such systems (Orr, 1992); and (3) perturbations of such systems will have consequences that may threaten the stability and sustainability of the system as a whole (Berkowitz et al., 2005).

The National Research Council (1996) describes being scientifically literate as using scientific knowledge and evidence to draw inferences necessary to make personal decisions. Duschl et al. (2007) expand on this definition by explaining that scientifically literate individuals are able to (1) know, use, and interpret scientific explanations of the natural world; (2) generate and evaluate scientific evidence and explanations; (3) understand the nature and development of scientific knowledge; and (4) participate productively in scientific practice and discourse. Uno and Bybee (1994) described four levels of biological literacy: nominal (knowing scientific terms); functional (applying scientific terms to phenomena); structural (transferring concepts to engage in scientific inquiry); and multidimensional (making scientifically informed decisions). It is clear that being able to *make* and justify decisions using scientific information is the hallmark of demonstrating scientific literacy.

○ Writing-to-Learn vs. Writing-to-Communicate

Although there are many instructional strategies to help increase students' scientific literacy, we have found, as others have, great success with writing-to-learn (WTL) activities (Wellington & Osborne, 2001; Hand et al., 2004; Saul, 2004). By integrating writing and reading activities into science courses, we can help students appreciate how scientists gather, interpret, and make sense of data, and how they communicate concepts (National Research Council, 2011). Writing helps improve scientific literacy because it allows students to develop evidence-supported arguments (Wellington & Osborne, 2001) and move from vernacular to scientific expression (Wallace, 2004).

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There are two types of writing activities teachers often assign in formal classrooms: WTL and writing-to-communicate (WTC). WTL differs from WTC in that the former centers on the process of organizing thoughts, evaluating supporting thoughts, and revising written thoughts; whereas the latter centers on the final written product and the method whereby it conveys a message. The most common WTC assignment in biology courses is the laboratory report (Mackenzie & Gardner, 2006), which assumes that students know how to identify evidence to support their claims, a skill necessary for scientific argumentation.

The three major genres of WTC essays that students most often learn in formal classrooms include (1) expository, (2) narrative, and (3) persuasive (http://www.corestandards.org). Expository essays reflect what students know about a topic and are usually devoid of opinion. These are often written in third person and are informative. They may use cited materials to support claims; however, these are not required. Most laboratory reports or library research papers are expository essays. Narrative essays, on the other hand, highlight the human perspective and are generally written in first person. These "story-telling" essays draw on subjective claims and emotive writing elements (e.g., evoking empathy). Examples of narrative essays are editorial pieces in newspapers or travel blogs. The third genre, the persuasive essay, shares many similarities with the scientific argumentative essay. Persuasive or argumentative essays often have clear position statements or claims, like an expository essay. However, these claims may be opinionated or positional. Often writers draw on many types of appeals (logical, emotional, and ethical) to convince the reader of the validity of the argument being posed. The organization of this type of essay is important because the flow of logic is an important rhetorical strategy to successfully convince the reader to share the same position as the writer. High-quality persuasive essays include a refutation of potential rebuttals. The strategies used in persuasive arguments are similar to those used in scientific arguments (Toulmin, 1958); however, scientific arguments do not necessarily draw on explicit emotional and ethical appeal. Besides scientific research papers, other examples of persuasive essays are those used by politicians or political lobbyists. These essays may be written in either first or third person, depending on the type (personal or scientific) of argument being posed.

WTL, on the other hand, requires that students reflect on their own writing through the use of teacher guidance, written guidance (i.e., prompts or graphic organizers), or opportunities to share and defend their ideas with peers. Iterative WTL activities allow students to reexamine their ideas and modify their supporting evidence as they construct a claim (Bereiter & Scardamalia, 1987). Commonly, iterative WTL activities in science classrooms tend to be of the "outline, draft, and final lab report" variety. However, we argue that these activities help hone students' declarative knowledge skills (recalling knowledge) and not their schematic knowledge skills, for which they must practice organizing knowledge (Furtak & Ruiz-Primo, 2008). We believe that other iterative WTL activities can support students' developing scientific literacy skills, especially if they involve engaging socio-scientific issues. Asking students to explore relevant scientific issues through multiple perspectives allows them to gain a better understanding of the concepts (Wallace et al., 2004). Hence, we recommend asking students to write iterative essays about one socio-scientific topic using all three WTC genres (expository, narrative, and persuasive).

○ What Are Socio-Scientific Issues?

Socio-scientific issues (SSIs) are scientifically and socially important issues with no clear right or wrong answers. Some SSIs may center on scientific discoveries, procedures, or products that may be used in ways that some people feel are morally inappropriate (e.g., some forms of contraception or stem cell research). Other SSIs are those in which a dilemma develops for the learner as scientific knowledge of the issue increases and challenges cultural/social norms (e.g., fracking or damming). Some SSIs are socially important because differing perspectives are represented in the media (teaching of evolution or evidence of climate change), even if scientists would argue that these issues should be not be presented as unstructured or debatable.

To make decisions about SSIs, people often draw on both scientific and informal personal reasoning (Sadler & Zeidler, 2005). Scientific reasoning assumes that one uses contextual evidence to support a claim without oversimplifying cause-and-effect relationships. By allowing students to explore topics using scientific reasoning (what they know about concepts and the supporting facts) and then informal personal reasoning (how they feel about a topic and what they personally experience) before asking them to make a decision (how to resolve the issue), we believe that we can scaffold the decision-making process.

○ Method: The CAB WTL Model

We developed our WTL model with careful deliberation and drew from our experiences teaching middle–high school science and undergraduate majors and non-majors courses in biology departments. In previous studies, Balgopal (2007) found that students who were able to resolve conceptual confusion and were best able to demonstrate an understanding of complex scientific issues chose to support their claims with both scientific *and* personal evidence. We knew it was essential that we chose writing-prompt topics that were engaging, emotionally relevant, and meaningful for our students. Moreover, because it is clear, through research on learning, that people learn using three domains – cognitive, affective, and behavioral (Bransford et al., 2000; Sousa, 2001) – we wanted to facilitate students' learning by guiding them to draw on all three domains through writing activities. What emerged from our efforts was the Cognitive-Affective-Behavior Writing-to-Learn (CAB WTL) model, which allows students to explore issues from different angles. Students are asked to write three iterations of essays in response to prompts that elicit what they (1) know (expository essay); (2) feel (narrative essay); and (3) want to do to potentially resolve or respond to the SSI (persuasive essay; Figure 1). We have found that students who are engaged in writing activities with various purposes gain a better appreciation for both the social and the scientific significance of an issue. In addition, K–12 science teachers are able to support the efforts of language-arts teachers by meeting goals of the Common Core English Standards used across the United States (http://www.corestandards.org/the-standards/english-language-arts-standards).

For the past several years, we have tested variations of this model in various contexts (middle school, community college, university). By carefully choosing reading assignments that are accessible to each group of students, we begin the activities by introducing place-based SSIs to the students. During the WTL activities, we have tested various types of guidance – by teaching students how to concept-map

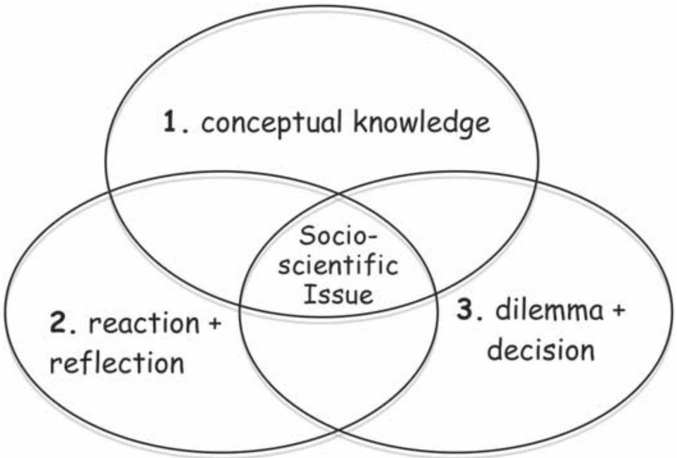

Figure 1. Students are asked to write three essays in response to prompts about a socio-scientific issue. Essay 1: What do you know about this issue? Essay 2: How do you feel about this issue? Essay 3: What will you do or should others do to resolve any dilemmas related to this issue?

important facts along with reflective responses prior to writing activities (Balgopal & Wallace, 2009), by fostering in-class discussion with peers and between students and instructor, and by developing writing prompts that allowed students to be creative in their responses by taking on different personas or "voices" (Balgopal et al., 2012).

○ Examples of SSIs to Use for Writing Prompts

Hypoxia

Much of our work centers on what students know, feel, and decide regarding ecological SSIs. One example is aquatic hypoxia (see Appendix). Aquatic hypoxia results after nitrogenous fertilizer run-off accumulates in water systems, causing a disruptive chain of events that results in a dead zone along coastal areas (Raloff, 2004a, b). This topic is particularly relevant to residents who live near the headwaters of the Mississippi River. In our studies of Minnesota undergraduates, this topic elicited much interest, passionate discussions, and strong emotions. For example, about half of the students had immediate ties to farming and felt defensive of farmers who are often implicated in discussions about hypoxic dead zones, and Ojibwe students from the tribal college felt that humans had a responsibility to keep their behavior in check if the effects on the environment were negative.

Genetically Modified Crops

Another locally important topic is genetically modified organisms (GMOs). Students read about GMO crops (National Academy of Sciences, 2010) that are engineered to have beneficial traits to overcome environmental conditions (cold tolerant, herbicide resistant, or less susceptible to insect herbivory). They explored tradeoffs between environmental and economic risks and benefits. Some scientists argue that the risks are real: that GMO crops may be responsible for disrupting natural ecological trophic systems through cross-pollination (Rosi-Marshall et al., 2007).

Ocean Acidification

Our students live far from the ocean but are fascinated by it. Ocean acidification is caused by anthropogenic carbon dioxide in the atmosphere that reacts with water, forming carbonic acid (H_2CO_3), weakening shells or skeletal frameworks of coral and foraminifera. Although ocean pH is only one part of the puzzle of why marine ecosystems are changing, it is clearly an important part of the story (Zimmer, 2010).

Meat Consumption

Meat consumption is also related to anthropogenic carbon dioxide. Bittman's (2008) argument is that through the agricultural efforts of raising cattle (use of fossil-fuel-burning farm equipment) and the gaseous waste produced by cattle after consuming a grain-heavy diet, Americans' obsession with beef consumption is contributing to the build-up of greenhouse gases and dependence on nonrenewable resources. This SSI prompted students to question their own eating habits and was, therefore, deeply personal.

Management of Endangered Species

Our middle-school-teacher research partners chose the issue of managing global and local endangered species. Writing activities were tied to a field trip that their seventh-grade students took to a large urban zoo where the students took a class on endangered animals (Gilbert et al., 2010). Students learned that all organisms, including humans, compete for resources in order to survive. When human development or perturbation of natural environments occurs, many nonhuman animals must compete with humans for limiting resources. Students chose two case studies to explore, one global and one local, and wrote about their similarities and differences.

○ Examining Student Writing

The CAB WTL prompts students to use various types of evidence and/or types of reasoning (scientific or personal) to describe a dilemma about an SSI. Essays can be examined on the basis of the types of evidence that students use to support their claims (Table 1). Essays that do not make a clear claim or draw on evidence to support a claim are classified as superficial. Essays that draw exclusively from personal examples or experiences are classified as subjective. Those written in an objective manner that draws primarily on scientific evidence are classified as objective. As instructors we hope for students to demonstrate writing that draws on both personal and scientific evidence to support claims; such essays are categorized as authentic.

○ Findings

This model is not only a valuable instructional strategy for our students but serves as an informative feedback indicator for our own teaching. Not every student who writes a series of three guided essays demonstrates that they have reached complete scientific literacy, but rather the essays allow us to detect movements along a scientific literacy spectrum among different student populations.

Undergraduate Elementary Education Students

These students showed a great deal of flexibility in their writing (Balgopal & Wallace, 2009; Balgopal et al., 2012). Many were quick to personalize an SSI and expressed personal connections in their

Table 1. Literacy level was coded by characteristics of the written discourse, in terms of the types of supporting evidence and connections that students provided (Balgopal & Wallace, 2009).

Literacy Level	Characteristics of Written Discourse
Superficial	Little to no evidence of personal or cognitive connections; disconnected ideas showing no clear conceptual or affective understanding of the issue
Subjective	Discloses personal (*affective*) connections but does not necessarily demonstrate conceptual understanding
Objective	Demonstrates *conceptual* understanding but does not necessarily disclose personal connections or prior experience
Authentic	Demonstrates and integrates conceptual understanding and personal connections and *behaviors* related to the issue in a way that demonstrates scientific literacy

essays. We discovered that essays were more variable when there was less guidance (i.e., essays given as take-home assignments with little or no discussion in between). These students were equally likely to be subjective writers as they were to be authentic writers and were less likely to demonstrate high levels of scientific literacy. Sixty-four percent of the students who received considerable guidance (n = 22), including concept-mapping activities, were more likely to write authentically and demonstrate a higher level of scientific literacy by their third essay.

Undergraduate Biology Students

Not surprisingly, biology majors wrote more objectively in all three of their essays (Balgopal et al., 2012). Nearly half (n = 42) remained "stuck" in this place along the scientific literacy spectrum, despite prompts that encouraged them to incorporate personal and societal perspectives into their writing. They frequently wrote in the third person and invoked a nonspecific "other" to address environmental problems in a dispassionate way. However, this generalized response was observed mainly in students who received little guidance. In an unpublished study, when students (n = 13) received more guidance and opportunities for student-led discussions, more of them wrote authentically by their third essay, but this was dependent on the SSI. Students who wrote about GMO crops or meat consumption tended to write more subjectively. We attribute this to the personal nature of these issues, compared with hypoxia or ocean acidification. When given a new issue to investigate and asked to write a transfer essay in a style of their choosing, many of these students wrote objectively.

Native American Tribal College Students

Many of the tribal college students initially wrote subjectively; however, with in-class guidance (discussions about concepts and related inquiry activities), about half increased their scientific literacy (Balgopal et al., 2012). They drew on personal experience and perspectives to support their decisions. From our initial analyses of the types of reasoning that Native American and non-Native students used to justify their claims about the same SSI, we have found that values and attitudes influenced the types of decisions made. Seventy percent of the Native students (n = 23) considered environmental costs compared to economic costs, whereas 71% non-Native students (n = 24) responded the opposite, making decisions that favored economic issues over environmental ones.

Middle School Students

Working closely with two middle school teachers (one science and one English), we reinforced to the students that the three iterations of the CAB WTL mirror the three school-district-required genres of written discourse: expository, narrative, and persuasive. Our teacher research partners spread the writing activities out over a longer unit on "limiting resources and population growth," during which they integrated inquiry activities and plenty of time for in-class discussion, writing, and editing.

We found that 21% of the students demonstrated an increased knowledge of limiting resources, 18% an increase in recognition that humans are a part of ecosystems, and 15% an increase in decisions about personal behavior to resolve perceived problems compared with their pre-unit essays. We modified the activities by developing graphic organizers for students to help them identify claims and evidence within the reading assignments. Then students used the same graphic organizer to plan their own written discourse. We found this strategy to be particularly useful for students whose writing skills are still developing and for whom English is not a first language (40% of our sample).

○ Discussion

Our various studies of the CAB WTL with different student populations make us confident that this model, like others, has great potential to increase students' knowledge about socio-scientific issues and, consequently, their scientific literacy. In guiding students through a sequence of writing activities, we encourage them to consider (1) what concepts are central and essential to understanding the issue, (2) how they feel about the issue and connect to it, and (3) what decisions they or others might make to resolve any emergent dilemmas regarding the issue. Iterative writing activities such as what we describe are often overlooked in secondary and post-secondary science classrooms, yet we argue that they can be valuable mechanisms for increasing scientific literacy – both content understanding and ability to make data-informed decisions.

Furtak and Ruiz-Primo (2008) explained, in their study of assessment strategies, that the combination of writing (which allows for individual student feedback but is delayed) and in-class discussion (which provides immediate feedback but may not represent all student views) is the most effective way to assess students in a science class. Rivard and Straw (2000) similarly found that writing plus talking (small group and class discussion) resulted in higher understanding of environmental issues by middle school students than when they were engaged only in writing activities. Therefore, the take-home message that we advocate is that writing can be a powerful instructional and learning strategy that, when paired with instructor guidance through meaningful prompts around socially important biological issues and discussion, helps students increase their scientific literacy. We encourage science educators to go "beyond the lab report" and consider the value of helping students use writing to explore their understanding of SSIs and their affective responses to these issues. In-class discussions allow students to hear other students' perspectives, concerns, and ideas about the same issue. Because most SSIs do not have clear answers, it is important for educators to scaffold opportunities for our students to use their analytic and evaluative skills to identify tradeoffs of potential decisions they might make. Writing allows students to see what they know and revise their conceptions and perceptions, and it allows instructors to tailor their instruction to encourage the active revision of these conceptions and preconceptions in such a way as to demonstrate scientific literacy.

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Appendix: Examples of Some Writing Assignments.

SSI: Hypoxia
Essay 1
Write a brief article about hypoxia, designed to educate a target audience of your choosing, that could be published in a newsletter or newspaper. This article should be informative, with the goal of educating readers about what hypoxia is, what causes it, and what the consequences are. (*Class discussion and peer review*)
Essay 2
Write a blog entry in which you imagine how someone who is affected by hypoxia (e.g., a farmer, fisherman, homeowner, student, or fish) feels about this situation. Add a response comment to this blog by a reader who is either (a) yourself or (b) someone else who may also be interested and/or affected by hypoxia. (*Class discussion and peer review*)
Essay 3
Clearly articulate a large or small dilemma that either (a) someone who affects or is affected by hypoxia might have or (b) you might have regarding hypoxia. Write an essay that explains how this dilemma is related to hypoxia, how it might be resolved, and a decision reached (i.e., what to actually do!).
Transfer Essay
(Choose either meat consumption or ocean acidification, *following student-led class discussions*) Familiarize yourself with the issue by watching the posted video and looking up information on the Internet. Select one article written for the general public, and one scientific article published in a peer-reviewed journal. Have a small group discussion in which you (a) go over the science that is necessary to understand the issue, (b) describe the systems that are contributing to this issue, (c) describe the systems that are affected by this issue, and (d) identify individuals affecting and affected by this issue. In class, write a 2-page essay in a style of your choosing on this issue.