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Writing to learn ecology: a study of three populations of college students

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Being an ecologically literate citizen involves making decisions that are based on ecological knowledge and accepting responsibility for personal actions. Using writing-to-learn activities in college science courses, we asked students to consider personal dilemmas that they or others might have in response to how human choices can impact coastal dead zones around the world. We explored how undergraduate students (42 biology and 47 elementary education majors at a 4-year college and eight Native studies majors at a tribal college in the United States) identified their ecological dilemmas after reading about aquatic hypoxia. About 30% of the 4-year college students's essays demonstrated a more ecologically literate understanding of hypoxia by the end of the study. The tribal college students improved their ecological literacy by 50%, albeit with a small sample size. Biology majors made more human-centered comments than the education majors. The Native American students often discussed trade-offs between quality of life and ecological consequences, and were classified as both human-centered and ecosystem-centered.

Keywords: ecology; learning; writing; environmental issues

Introduction

It is important for students to understand the complexity of ecological systems, as well as to become informed decision-makers, if they are to become supporters of sustainable practices (Davidson 2003; Jordan et al. 2009; Orr 1992; Slingsby 2001; Stone and Barlow 2005; Walshe 2008). Being an informed environmental steward involves acceptance of personal responsibility for actions and an appreciation for how sustainable outcomes may be achieved. As college educators, we want to use strategies that encourage students to examine what they know and believe about a concept, and subsequently how they might use this knowledge as decision-makers.

Activities that are reflective, such as expressive writing, encourage students to be critical of their own understanding (D'Avanzo 2003). 'Expressive writing' is a style of writing that resembles how we communicate in everyday speech as it conveys information, reflects on information, and provides the opportunity for writers to make connections between prior conceptions and with new conceptions (Keys 1999). Moreover, when students have multiple opportunities to write, they consider

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what they know and believe as they expand, edit, and modify their previous draft, all of which help them become more knowledgeable (Bereiter and Scardamalia 1987). In this paper, we argue that writing-to-learn (WTL) ecology activities can help college students increase their ecological literacy by guiding them to examine what they know about ecological concepts and their own connection to ecosystems. The objective of this study, therefore, was to examine how different subpopulations of college students respond to WTL ecology activities and write about ecological dilemmas.

This study explores WTL ecology activities in three populations of students enrolled in different introductory biology courses: (1) non-majors (pre-service elementary education teachers) at a public state university; (2) science majors (biology) at a public university; and (3) Native American students (Native studies majors) at a nearby tribal 2-year college. Because the tribal college does not offer bachelor's degrees, the Native students were enrolled in a program designed to encourage them to transfer to the state university in order to receive a bachelor's degree. The alignment of courses for transfer was a fairly new program, and at the time of the study, none of the students had transferred their tribal college credits to the state university to earn a degree. Most of the Native American students seek jobs on the reservation as teacher aides because they do not want to leave their families or the reservation culture behind. We chose to include this population of students in this study because the science instructor worked closely with the two authors who taught the majors and non-majors courses offered at the state university and chose to conduct similar WTL ecology activities in his courses. In addition, we were interested in how a population of students from a different cultural and economic context would perform in the WTL ecology assignments.

We recognize that students in our study came from different cultural and educational backgrounds. In light of this fact, during our class periods we did not advocate prescribed behaviors that we hoped our students would exhibit because we did not want to impose our own cultural, generational, or economic biases regarding acceptable behaviors. Rather, our intention was to encourage students to take ownership of their own decisions about their personal behaviors and to understand the respective environmental consequences. We believe that through this approach, environmental stewardship will be more meaningful and long lasting, in part, because students will undoubtedly encounter environmental issues in the future that we cannot currently predict.

Background

Ecological literacy

We define an ecologically literate person as one who is able to make personal decisions using scientific knowledge about ecosystems (Jordan et al. 2009). In order to understand how ecosystems function, an individual must first have structural and functional knowledge of the biotic and the abiotic components of such systems (Magntorn and Hellden 2005; Norris and Phillips 2003; Slingsby 2001). Once individuals know how ecosystems function, only then can they recognize that humans are part of and can affect ecosystem dynamics (Orr 1992; Roth 1990). In this regard, some scientists, as well as science educators, do not distinguish between the terms *ecological literacy* and *environmental literacy* and may even choose to combine the two terms into a new one, *ecological thinking* (Berkowitz 2007; Magntorn and Hellden 2007; Orr 1992; see Cutter-Mackenzie and Smith 2003 for expanded review).

Despite the variations in terminology, researchers argue that it is becoming increasingly important for individuals to be knowledgeable about ecological concepts, if they are going to make informed decisions about the conservation of natural resources and stewardship of natural and managed ecosystems (Barrett 2001; Berkowitz, Ford, and Brewer 2005; Bruyere 2008; Jordan et al. 2009; Slobodkin 2003; Stone and Barlow 2005). Therefore, being ecologically literate requires both being knowledgeable about ecological concepts, as well as being able to make personal decisions using that knowledge. Some environmental educators argue that through increased ecological knowledge and ability to use this information to make decisions about personal behaviors, students can better understand the complex social, economic, and scientific issues that are central to the concept of sustainability.

Many studies on ecological knowledge have centered on concepts such as: ecosystems interactions, food webs, evolutionary adaptations, carrying capacity/population growth, and the niche concept (e.g. Adeniyi 1985; Hellden 2004; Leach et al. 1996; Munson 1994; Stamp 2005). In his survey of the British Ecological Society, Cherrett (1989) found that ecologists ranked *ecosystems* as the most important of 50 ecological concepts that were identified. It is not always easy for students to develop deep understanding of ecosystems. In their study on ecosystem understanding, Magntorn and Hellden (2007) found that even with explicit instruction on materials cycling, trophic levels, and succession, some students were unable to transfer their understanding of complex functional roles that biotic and abiotic factors play in a 'novel' ecosystem to which they were exposed. In general, they suggested that some students find material cycling and energy flow through systems to be abstract concepts, perhaps because they are not visible to the eye (Magntorn and Hellden 2007; Lawson et al. 2000). Hamilton-Ekeke (2007) found that when Nigerian secondary students who participated in outdoor instruction on ecosystems demonstrated a significantly higher level of knowledge than control groups. In summary, teaching about ecosystems is important if students are expected to understand the impact that people can have on disrupting natural systems.

Students must go beyond a basic appreciation for interrelatedness of life and the world as a physical system and should be able to articulate how their decisions can have an impact on ecosystems (Bruyere 2008; Jimenez-Aleixandre and Pereiro-Munoz 2002; Orr 1992; Schneider 1997). Studies indicate that decision-making about environmental issues involves value and belief systems (Grace and Ratcliffe 2002; Littledyke 2008). In their study of Spanish secondary students' learning and argumentation about wetland conservation issues, Jimenez-Aleixandre and Pereiro-Munoz (2002) found that decision-making involved more than just ecological knowledge. Students drew on their value systems and often placed higher value on ecological concerns over economic ones. The authors suggested that in order to be able to participate in decision-making citizens do not need to know everything about an ecological issue. Rather, they acknowledged that different people likely take different positions about how to address ecological issues based on their own expertise and perspectives. In a similar vein, Littledyke (2008) argued that science teachers must use pedagogical strategies that recognize both the effective (cognitive) and affective domains if they expect their students to become 'ecologically sensitive, with the potential for informed pro-environmental behaviour' (8).

Indigenous ecological knowledge

Because values and belief systems affect how people perceive ecological issues and the natural world, it is essential to acknowledge the role that cultural worldview may play in learning about ecological science. Indigenous cultures typically have developed an intimate relationship with and understanding of their natural world, which has helped shape an indigenous worldview (Cajete 2000; Snively and Corsiglia 2001). There are different ways of knowing that are culturally bound: traditional ecological knowledge (TEK) and western modern science (WMS), which Snively and Corsiglia (2001) argue are often at odds with one another. Where many Native peoples have extensive naturalistic traditions that have been learned through observation and personal experience (Nelson-Barber and Estrin 1995), WMS has a long history of studies that are repeatable and documented in published periodicals. Bowers (2001) reminds us that WMS often uses metaphors and language of controlling and directing nature, unlike the language used by many Native peoples of North American. Cajete (2000) explains that Native people embrace an eco-philosophical interpretation of their natural world for which cosmology, philosophy, values, and action all intersect. The 'ecological person' is not above his/her natural world but rather part of the whole, working to maintain balance (Cajete 2000; Nelson-Barber and Estrin 1995). Aikenhead (1997), in his study of First Nations (indigenous) students in Canada, explained that WMS can be viewed as 'a hegemonic icon of cultural imperialism' to indigenous people and that their ecological ways of knowing is drawn from both experiences and perceptions, as well as from dreams, visions, and signs. These sources of data are classified as pseudoscience, however, to those who study the world using a WMS perspective. For a more comprehensive review on TEK see Van Eijck and Roth (2007). Therefore, it is imperative for ecology educators to identify instructional strategies that are culturally sensitive and not dogmatic, if we hope to help all students become more ecologically literate.

Writing-to-learn

Instructional strategies that require students to build upon their prior knowledge and find direct relevance of new knowledge can be meaningful for learning (Bransford, Brown and Cocking 2000). WTL activities, in particular, can capture the affective and behavioral connections that students make when studying science (Bereiter and Scardamalia 1987; Liu 2004). Researchers argue that language-based activities have been underused in the sciences to promote learning, even though it has been recognized that reading and writing activities can help students acquire new knowledge, as well as help them clarify and connect scientific ideas (Mason 1998; Rivard 2004; Saul 2004).

Science educators and researchers have advocated the need for students to read and write in genres other than laboratory reports in order to become more scientifically literate (Rivard and Straw 2000; Mackenzie and Gardener 2006; Ritchie Rigano, and Duane 2008). Prain (2006) suggested that if teachers encourage their students to use everyday language to express themselves, it helps them build upon their prior knowledge. Dlugokienski and Sampson (2008) purported that reading and writing activities help middle school science students become more educated decision-makers, ready to participate in democratic activities and processes. Hand, Wallace, and Yang (2004) have been successful promoting writing in science content using a Science Writing Heuristic (SWH) and found that middle school students performed better on conceptual questions than their peers after participating in writing activities. Hand, Wallace, and Yang (2004) argued that writing required these students to use meta-cognitive and self-reflective skills, helping them to understand the science concepts better than a control group. The SWH has been shown to help high school students learn science concepts, as well (Hand, Hohenshell, and Prain 2004). The SWH allows students to consider what their personal conceptions for a laboratory exercise are, then share these with classmates before finally comparing their group ideas with those found in the published literature. Through writing students can determine how meaning about science is made, as well as 'see' how their own ideas have evolved over the course of the science unit.

Similarly, at the college level, Balgopal and Montplaisir (2011) found that reflective writing assignments in an undergraduate ecology course helped students make meaning of newly learned concepts by allowing them to apply the concepts in their own words. Students explained during interviews that when they participated in writing exercises it enabled them to determine what concepts were still unclear, as well as, how they needed to best support their claims using examples learned from class discussion and readings (Balgopal and Montplaisir 2011). Because students were able to examine their own developing conceptions through writing many felt that they developed a more robust understanding of the ecological concepts after the writing assignments.

Disciplinary disposition has an effect on the strategies that students use to write about science. In her study of the transferability of communication (writing) skills across disciplines in a history of science class, North (2005) found that arts and sciences college students have significant epistemological differences that are reflected in their written discourse. North noted that some major differences that existed between these two cohorts, co-enrolled in the same course, included: science students tended to accept the claims of the writer in academic articles, whereas arts students attributed the ideas to the author; science students were less likely to write about concepts from a balanced perspective, whereas the arts students presented multiple perspectives; science students wrote single iterations that may have undergone one round of final editing, whereas the arts students described writing multiple revisions; science students had difficulty of writing within the word limit (generally, writing very brief papers), which was significantly different than the arts students, who were better able to use the word limit to construct their argument and provide detailed evidence. In general, North (2005) concluded that science students demonstrated a factual conception of knowledge, unlike the 'relativistic epistemology' that arts students demonstrated. In the same vein, the science students who wrote very factually may not have been as capable of articulating their ideas about the economic, social, and cultural factors that influenced the history of science.

Based on our own studies on writing activities with non-science majors, we know that reading and writing specifically about ecological concepts can help students attain a higher level of ecological literacy (Balgopal and Wallace 2009). We developed a writing heuristic (Cognitive-Affective-Behavior Writing to Learn Model: CAB-WTL) grounded in the premise that students can demonstrate their ecological literacy by describing informed decision-making when participating in

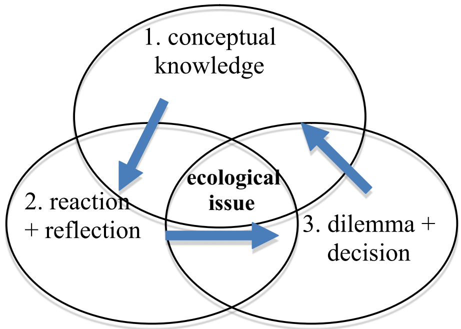

Figure 1. Cognitive-Affective-Behavior Writing-to-Learn Model (CAB-WTL).
Note: CAB-WTL requires that students write multiple iterations of reflective essays about a scientific prompt (e.g. ecological issue, such as hypoxia). In the first essay students only write about what they know and understand based on reading assignments and/or inquiry activities. In the second essay they write about how this knowledge makes them feel or might make another community member feel (e.g. Gulf coast fisherman). In the third essay students identify a personal dilemma and describe how they might resolve this dilemma.

iterative writing assignments around a central prompt (Figure 1). The CAB-WTL model incorporates three different domains of learning (cognitive, affective, and behavioral), while much of college science instruction is geared towards the cognitive domain of learning and knowledge retelling. We designed our activities with the intention of prompting students to write authentically about ecology by asking them to discuss how they may resolve an ecological dilemma using ecological content knowledge. Hence, the objective of this WTL model is to encourage students to use ecological knowledge with which to make decisions when resolving a dilemma.

Dilemmas often arise when conceptual understanding and affective responses to socio-scientific issues are in opposition, and a decision about what to do regarding an environmental issue is not readily apparent (Balgopal and Wallace 2009). Hence, for an individual to describe an ecological dilemma, he/she must be able to articulate their conceptual understanding, recognize personal and societal connections to the ecological phenomena, identify potential trade-offs, and, in some cases, acknowledge decisions about behaviors that would resolve the dilemma.

In a prior study, also with elementary education majors at the same 4-year college at which some of our current study was conducted, we allowed students to read, discuss, and write during class time, supporting the claim that social interaction and active discussion about concepts helps students make sense of their ideas (Wilkinson and Silliman 2000). By fostering discussions about their ideas, students were given an opportunity to form their positions and defend them as they talked to peers or faculty members. In that study, 67% of Education students demonstrated greater ecological literacy through their writing. We posit that in the former study students were able to work through their understanding of the ecological, economic, and social consequences of fertilizer run-off in rivers when they interacted with one another. A question that emerged from the findings, though, was whether different populations of college students would respond in the same manner to the writing assignment. In addition, we wondered how ecological worldview would influence the type of dilemmas and decisions that students choose to discuss in their essays. These questions prompted the current study.

Similar to North's (2005) findings, we recognized that our own students (science and education) communicate ideas differently. From our experience of assessing student writing in laboratory reports and short essay assignments, and from our class discussions, we anticipated that the three populations of students in this study would write about ecological issues differently. We hypothesized that biology majors would write in an objective manner because this is how they have been told to write laboratory reports, the most common genre in science discipline courses. We hypothesized that the education majors would write in a subjective manner based on our experience teaching these students. At both the institutions where this study was conducted, as well as others, it is common for pre-service elementary teachers to exhibit some apprehension about learning science content. As a result, when there are opportunities to reflect or provide opinions about topics, these students are willing to be articulate because they feel comfortable. The Native students, from our experience, have a worldview that is holistic; therefore, we hypothesized that their writing would reflect a more system-centered view.

Objective

The objective of this study was to examine how three populations of undergraduate students (biology and elementary education majors at a public 4-year college, and Native studies/general studies majors at a tribal college) identified and resolved their ecological dilemmas after participating in WTL activities. More specifically, we asked the following questions, as we analyzed the written work of each cohort.

(1) How do students draw on ecological knowledge to describe an ecological dilemma and related decision to resolve this dilemma? (In other words, how ecologically literate are students in each of the three cohorts?)
(2) How do students' essays (i.e. students' ecological literacy classifications) change over the course of the WTL study?
(3) How does ecological worldview differ between the three cohorts of students?
    (a) Do dilemmas that students describe reflect ecosystem-centered, community-centered, or individually centered concerns?
    (b) Do decisions that students describe reflect their ideas about personal action or actions that others should take?

Methods

Two sections each of introductory biology laboratory (for biology majors) and general biology (for elementary education majors) at a 4-year undergraduate institution and one section of general biology (for Native studies majors) at a tribal community college were selected to participate in our study. Students received one or more articles, and written instructions with little instructor guidance on the three essay assignments (see Appendix 1 and Appendix 2 for written instructions). Students received the instructions for essay writing in class and were able to ask for clarification but did not complete the actual writing during class time, although the tribal college students were given time to use computers in class. Instead, during class time students engaged in inquiry activities, listened to lectures, and participated in class discussions about ecological issues; however, the conversations with the professor did not center on the writing activity and associated readings per se. Rather, students were told to find classmates with whom they could discuss the writing prompts.

Students at the 4-year college were asked to read two *Science News* articles about hypoxic waters and dead zones, along with a hypoxia fact sheet published by the Ecological Society of America (Raloff 2004a, 2004b). The tribal college students read a *World Watch Institute* article that described hypoxia, along with other ecosystem issues (Bright 1999), which the professor had already chosen for his course. The Bright article described the scenario of hypoxic zones in a very similar manner to the Raloff articles, but described other ecological phenomena. We chose to focus on the ecological crisis of hypoxia and aquatic dead zones because of its local relevance (both colleges are geographically close to the headwaters of the Mississippi River), as well as its global importance (Raloff 2004a, 2004b; Diaz and Rosenberg 2008).

The articles that students read described several ecological concepts necessary for understanding the larger issue of environmental hypoxia, including: limiting resources, population growth dynamics, trophic levels, predator–prey interactions, dispersal behavior, nutrient cycling, and the effects of invasive species on ecosystems. If students described hypoxia, we expected them to write about the aforementioned issues in their essays. Hypoxic or 'dead' zones are increasing around the world, and more than 245,000 km^2 have been identified as being affected (Diaz and Rosenberg 2008). Much of the affected areas include estuaries and coastal marine ecosystems (Diaz 2001). Anthropogenic fertilization of watersheds (from agricultural run-off, for example) as well as other stressors associated with major human population centers are thought to contribute to the oxygen depletion in coastal waters. Increasingly higher levels of nitrogen that enter the watershed lead to a cascade of events which eventually disrupt populations of native plants, invertebrates, and vertebrates (Raloff 2004a). Nitrogen run-off allows planktonic algae populations to thrive, which provides rich organic material for microbial respiration. The sudden explosion of bacterial populations depletes the available dissolved oxygen, affecting benthic fauna. Many native fish species populations along coastlines have plummeted, allowing invasive aquatic species (such as jellyfish and some shark species) to replace native ones (such as shrimp and some fish species) (Raloff 2004b). The economic consequences have mostly affected fisherman and eco-tourist industry workers.

In the simplest sense, the dilemma that might arise for Midwestern farmers is to determine whether they should decrease their fertilizer use, which would decrease the effects of hypoxia on Gulf coast waters but at the expense of their own agricultural yield. The economic costs of decreasing fertilizer use may or may not outweigh any dilemmas (or guilt) about environmental (dead zones), and economic (decreased yield for Gulf fisherman) consequences.

Coding

Two authors read and scored 291 essays, three from each student (biology majors = 42, education majors = 47, Native studies = 8). The ecological literacy-coding scheme that we used in this paper was developed as a result of prior work on how students use supporting evidence in their writing (Balgopal and Montplaisir 2011; Balgopal and Wallace 2009). The development of our literacy codes was informed by the work of Wallace (2004) and Levin and Wagner (2006). Wallace proposed a theoretical framework to study scientific discourse that is presented in every day language. Using the dimensions of authenticity, multiple discourses, and Bhabha's 'third space' of common meaning, Wallace described that writers move from private to public discourse spaces in terms of (1) how they express their thoughts; (2) voice (self-talk or authoritative) that they use; and (3) their willingness to find common ground with their reader. In addition, Levin and Wagner (2006) explained that writers may or may not view writing to be open discourse spaces, which will affect whether they want to find common ground (i.e. persuade the reader to understand the writer's point of view). Levin and Wagner described four dimensions of written discourse: cognitive, affective, social, and meta-cognitive (see Levin and Wagner 2006 for further description). When writers perceive writing to be a closed process, the authors posited, they were less revealing in their essays. A learner who exhibits all four of Levin and Wagner's dimensions, though, would be considered to be *authentic*, based on Wallace's definition. In other words, an *authentic* writer is one who can find common meaning between him/herself and his/her reader by describing an argument that is supported by evidence and uses a voice that is accessible to the reader.

We coded essays as *superficial*, *subjective*, *objective*, or *authentic*. *Superficial* writers did not make any meaningful affective or conceptual connections to the ecological concepts being discussed. *Subjective* writers were able to make affective connections to the ecological concepts, but they were unable to support their ideas with ecological evidence. *Objective* writers, on the other hand, were able to demonstrate their understanding of ecological concepts. *Authentic* writers were able to make connections between reading material and class discussions in order to explain the ecological concepts to describe how they would resolve a dilemma (i.e. to make a decision). These students were also able to describe an informed decision that they (or others) might make based on their ecological knowledge and emotive responses to the ecological 'issue' described in the accompanying reading assignments and were deemed 'ecologically literate.' Therefore, being ecologically literate, in our minds, is a subset of being scientifically literate (Uno and Bybee 1994) (see Table 1).

Because we were not only interested in what students wrote but also in *how their writing changed with each essay*, we calculated how students moved between categories. We calculated the percentage of students who moved from each of the four categories to a different category. After our initial reading of each essay,

Table 1. Cognitive and affective affiliation model (CAAM) of learning (Balgopal and Wallace 2009).

	Cognitively distant	Cognitively close
Affectively close	Subjective	Authentic
Affectively distant	Superficial	Objective

Note: Affectively close students find personal connections with concepts; cognitively close students find connections that support the concepts presented in class. Distant students do not find connections with the concepts at all. Superficial students can find few affective or cognitive connections.

we recognized that different ecological worldviews emerged. When describing dilemmas in response to the writing prompt, students were not explicitly told what voice to use. Therefore, we were also able to code students' essays based on the perspective from which students chose to describe a personal dilemma.

To answer our questions about ecological worldview, we coded all of the essays based on: (a) whether the essay was ecosystem-centered, human community-centered, or individually centered (EC, HC_{us}, HC_{self}); (b) described a personal dilemma that the writer had (PD_w), or that someone else (fisherman or farmer-PD_f, or homeowner-PD_h) might have; and (c) if a decision to resolve the dilemma(s) was described (D). EC comments reflected the students' concern about ecosystem balance or disruption due to human activity. EC essays included comments that described the negative consequences of fertilizer run-off on ecosystems, of which students may or may not have described humans as being a part. HC_{us} comments, though, reflected the students' use of a plural active voice ('we') in reference to their (human) community being adversely affected by dead zones caused by hypoxia. HC_{self} comments reflected the students' use of a singular active voice ('I') in reference to the writer's personal life being disrupted because of the effects of dead zones (e.g. 'my relatives are farmers and are being blamed by city residents for causing dead zones').

There was an initial 85% inter-rater agreement between the first two authors. In some cases we did not complete our coding of an essay because we had difficulty following the thesis of the paper. In those cases, we read through the student's other essays to help us determine which code to use. In case where we had coded differently (often between subjective and superficial categories), we discussed whether the writer was actually addressing the prompt or not in order to come to consensus. The third author participated mostly in our discussion of the tribal college student essays and concurred with the coding of all groups of students. All three of us developed the ecological worldview categories, which we coded as a team.

This study is a part of a larger study in which we have been examining different prompts, guidance, and writing expectations. It is important to note some subtle differences in the instructional methods employed in the two settings in which the WTL activities were assigned: the tribal college and 4-year college. From our preliminary work with students at the tribal college, we discovered that the Native students were not always able to complete the assignments at home or in a timely fashion because of several reasons, including: no computers at home, lack of reliable transportation during the harsh winter months of the upper Midwestern United States, and problems with regular attendance due to child care issues. For this reason, the professor at the tribal college allowed time in class before or after instruction for students to work on their writing assignments. By focusing on writing about ecological issues during their science class, this may have allowed the Native students to focus on issues in their writing that the non-Native students did because they were told to complete their writing outside of class time. In addition, the writing prompts were written slightly differently for the two institutional populations, which may explain some of the differences in writing. The reason for this was the fact that different faculty members presented their assignments using different formats. We do not believe that the format is so different that it would account for differences in the writing, except, however, for the fact that the 4-year college students were asked to identify with a Midwestern farmer, homeowner or Gulf of Mexico fisherman. The Native students were not told to explicitly identify with anyone in particular. We do believe that this variation in writing prompt is important and are currently analyzing different data sets in which the writing prompts for different student cohorts is identical.

Findings

Ecological literacy codes

Students from all three cohorts (biology, elementary education and Native studies majors) wrote essays that could be categorized as s*uperficial, subjective, objective,* or *authentic* (Table 2) using the coding scheme described above.

The percentages of students that started in each of the four categories (*superficial, subjective, objective* and *authentic*) and then moved to a different category or remained in the same category by the third essay are presented (Table 3). None of the *superficial* or *subjective* students in either the biology or elementary education cohorts moved to the *authentic* category (i.e. demonstrate higher ecologically literacy) after the WTL activity. Twenty-five percent of the Education majors and 29% of the biology majors demonstrated ecological literacy by the third essay, and 6% of the education majors and 12% of the biology majors demonstrated ecological literacy by the first essay. Many of the biology majors started out and remained *objec-*

Table 2. Excerpts illustrating the categories of writing based on demonstrated ecological understanding of hypoxia, its causes and effects.

Category	Excerpt from 4-year college population
Superficial	Fisherman in the Gulf of Mexico have it hard. They rely on nature to provide them enough fish to be able to catch each season to make a living. Hypoxia makes it harder to be able to reach the fishermen's goal on how many fish needs to be caught…Also, hypoxia causes over fishing.
Subjective	I have several different emotions that come over me when discussing hypoxia and today I'm going to let them all out because I know that you guys will listen. The first is anger. It upsets me that the main cause of this whole situation is some arrogant farmers up in Minnesota. They are only concerned with making sure that their crops are plentiful and they don't bother to consider how their over fertilizing may affect other people and the environment. It is unlikely that they will go out of their way to change their farming techniques because hypoxia is not affecting them directly. I hate that I am almost helpless in this situation…
Objective	The problem, hypoxia, happens because of algae blooms. This all begins because of nitrogen that runs off of fields from excess fertilizer. The rain washes it into rivers and streams. It ends up in the mighty Mississippi river and flows down into the Gulf of Mexico. The extra fertilizer causes algae bloom. There isn't enough fish and aquatic life to eat all the excess algae. The extra algae then decompose and a bacterium grows. This decomposition uses oxygen. This means that the water around this bloom becomes oxygen deprived and aquatic life cannot survive. Now there are huge dead zones where there are not fish at all.
Authentic	Just like the over usage of nutrients upsets the ecosystem, the continuation of the dead zone will upset the economic system that will eventually affect everyone in the United States. It just further proves that each and every one of us needs to do our part in helping save the planet. Some may ridicule us for buying into the 'green' way of life, but all of our actions have consequences…

Table 3. The percentages of biology majors' (n = 42) and elementary education majors' (n =47) essays which were coded as *superficial*, *subjective*, *objective*, or *authentic* as part of a WTL activity.

BIO = 42		Third essay			
First essay		Superficial	Subjective	Objective	Authentic
	Superficial	7		2	
	Subjective		2		
	Objective		7	43	17
	Authentic				12
EL ED = 47		Third essay			
First essay		Superficial	Subjective	Objective	Authentic
	Superficial	6	4		
	Subjective				
	Objective	13	23	23	23
	Authentic		4		2

Note: *Authentic* writers were considered 'ecologically literate.'

tive writers (43%), yet 17% became either more *subjective* or *authentic*. Many of the Education majors who started out as *objective* writers shifted to one of the other three categories. In other words, there was more variation within this cohort.

When combining the data sets from the 4-year college student essays, we found that about a third (28 of 89) of the students demonstrated an authentic understanding of hypoxia by the end of the WTL activities in at least one of the three essays (Table 4).

Half of the tribal college students demonstrated greater ecological literacy by their final essay; however, the very low sample size (due to the low reservation population, poor attendance due mainly to transportation issues during the winter and child care issues) is an important factor to note (Table 5).

We coded on content and not based on the writer's ability to use correct grammar and syntax. In one set of essays, written by a non-native English speaker, who made many grammatical errors, the writer demonstrated her *authentic* understanding of the ecological concepts that are central to the dead zone issue. The writer was also able to emotionally connect with the ecological issue, as demonstrated in the following excerpt:

Table 4. The percentage of each cohort and combined cohorts that was coded as *authentic*.

Population (#)	Essay 1 (%)	Essay 2 (%)	Essay 3 (%)	n
Combined (89)	29	25	46	28
Biology (42)	19	38	44	16
El education (47)	42	8	50	12

Note: Both biology and elementary education cohorts had writers that were coded as *authentic* during all three essays; however, only a third of the combined population demonstrated *authentic* ecological understanding (28/89) by the third essay.

Table 5. Percentage (and number) of tribal college students' essays that were coded *superficial*, *subjective*, *objective*, or *authentic*.

		Final essay			
First essay		Superficial	Subjective	Objective	Authentic
	Superficial				
	Subjective		47% (3)		
	Objective		12% (1)		50% (4)
	Authentic				

Note: Students bifurcated and were coded as either *subjective* or *authentic* writers by the final essay. $N = 8$.

> I said [to a midwestern homeowner] I am not asking you to stop using all these beverages [car, electricity, fertilizing plant] but eliminate them as much as you can, for healthier environment and nutritious food, and better future for our kids. Unfortunately, if this person didn't care well, like many others, it will be a problem for every individual in the future, I am raising three kids. I will be worry about there future if they will lack of iodine, iron, and any other natural vitamins they could gain from eating seafood, what the environment? What would the sea look like without any living animals being their? I am not sure by then if swimming will be safe. It does not seem smiley future for me or for later generation. If the sea animals can't live in there home water, then we may face the same problem on earth after many years from now, how knows! We are facing enough problems in our resent days from increasing fuel, food prices, and economy declivity. We should all act and do our part for a better environment [sic].

Ecological worldview

Biology majors were more HC than the Education majors were (Table 6). HC comments can be illustrated by the following excerpt,

> If we don't all worry about the problem going on with hypoxia there will no clean water for your family to play in. Furthermore, what about the jobs that will be lost if people are no longer able to fish in the Gulf or vacation on the Gulf. . .the whole economy would suffer.

Some of the HC comments fell into a community-centered attitude (HC_{us}), while others were more self-centered (HC_{self}). Many writers were concerned that one human food source (grain crops) was being supported at the expense of another human food source (fish). 'We are killing off a main source of food, which is fish, to produce crops, which is another source of food. So, using fertilizer with nitrogen is a lose–lose situation.' We coded this as example of being human-centered because other organisms (plants and fish) were perceived as being important primarily because they provided food for humans.

Comparing the predominantly Euro-American students at the 4-year college with the Native students at the tribal college, we found that the Euro-American students discussed trade-offs between the maintenance of the quality of life versus job security (e.g. of farmers who use N-based fertilizers that run off into rivers, which drain into Gulf waters). Alternatively, the Native students discussed trade-offs between

Table 6. A comparison of biology and elementary education essays based on whether they were more human-centered, ecosystem-centered, or both.

	Human-centered (0,1) 0 = not at all; 1 = yes	HC 'type' 1 = 'self'; 2 = 'us'	Ecosystem-centered 0 = not at all; 1 = yes
Biology majors (42)	0.95	1.36	0.29
El education majors (47)	0.77	1.11	0.45

Note: Essays were coded based on whether they were more human-centered, ecosystem-centered, or both. Human-centered essays were then categorized as 'self,' meaning that the writer was mainly concerned about how his/her life would change because of the prevalence of dead zones, or 'us,' meaning that the writer was concerned about how a community or a population of people would be affected by dead zones. When values exceed 1.0 students made several comments that could be classified in that category, as in the case of HC 'type.'

quality of life and ecological consequences. Unlike the 4-year college students, all of the Native students exhibited both HC and EC views. The 4-year college students' views ranged from no obvious orientation, HC, EC, or both.

Some students did not write about the effects of hypoxia and dead zones on their own lives (comfort, diet, job security); rather, they wrote about the effects on the ecosystem and were coded as being ecosystem-centered (EC). An example of an EC excerpt illustrates how the student's concern about ecosystem disruption, 'Too often we have sat by and done nothing while our ecosystem and living creatures have diminished.'

In the Native Studies student population, we found that students most often were coded as EC and HC_{us}. However, most of the HC_{us} statements appear to demonstrate the students' conception that humans are *part of* the ecosystem. 'This is an example of how we don't have the knowledge to anticipate the response one force can have on an ecosystem.' Another Native student pointed out that 'we won't begin to fix anything until it "really" affects us.' Most of the students from the tribal college described how humans have 'hurt' our world in order for our own convenience and because of a lack of understanding of connectedness. Moreover, Native Studies students used very emotional language to explain their dismay with human's lack of connection to the ecosystems of which they are a part. The following narrative demonstrates the student's affective connection to her ecosystem, in spite of her grammatical and syntactical errors:

> Communities have different relationships; each living thing depends on another for life…It angers me knowing that people have no respect for this earth. It's our only one, that is, no more tries have we wreck this one. People don't seem to realize this…Our ancestors seem to know all of this, they never wasted things and knew how to respect and take care of the earth.

Decisions: resolving dilemmas

Although students were asked to describe a dilemma that a community person (or themselves) might face when thinking about the ecological issues surrounding dead zones, not all students described decisions that people (or themselves) might make in order to resolve the dilemma. Both elementary education and biology students more often than not wrote about a dilemma from the perspective of someone else (i.e. fisherman or farmer; Table 7). Of the elementary education majors 64%, compared to only 48% of the biology students described a dilemma. Sometime students took the perspective of a farmer or fisherman. Sometimes they explained that it was not possible for them to change their own behaviors: 'the truth of the matter is I can't risk it [decreasing fertilizer use] right now; I need to do what makes my business run effectively and that may mean polluting the dead zone.' At other times, the writer gave solutions to solve the dilemma: 'by farmers using precision-farming methods farmers can still achieve the same if not better crop yields in exchange help the growing problem in the Gulf of Mexico.'

Although the biology majors used language that was community-oriented, they were still insistent that 'others' should fix 'the problem.' The following excerpt exemplifies these types of comments: 'the state is responsible for taking care of our fertilizers and waste waters.' Education majors were more EC than their biology

Table 7. A comparison of biology and elementary education students' descriptions of a dilemma that a community person might face when thinking about the ecological issues surrounding dead zones.

	PD_f (farmer or fisherman) 0 = none; 1 = yes	PD_w (writer) 0 = none; 1 = yes	Total PD $PD_f + PD_w$	Decisions 0 = none; 1 = other; 2 = self
Biology majors	0.36	0.12	.48	0.67
El education majors	0.49	0.15	.64	1.13

Note: Students in both the biology and elementary education cohorts were asked to describe a personal dilemma (PD) from either their own or someone else's perspective. Students were not asked to make a decision about how they would resolve the dilemma; however, some writers provided this information. The proportion of students who identified with either the farmer or fisherman (PD_f) or who identified with themselves (PD_w) is presented. Elementary education students were more likely than biology students to describe decisions to resolve the dilemmas and some described that others (often, the government), as well as themselves, should work towards reducing the dilemma. If values exceed 1.0 it is because students made several comments that could be classified in that category, as in the case of decision-making comments made by elementary education students.

major peers and were focused more on the 'self' for addressing the problem. The education majors discussed ways that they, as citizens, could resolve a dilemma, as opposed to suggesting that 'the government' should design and enforce regulation of nitrogen run-off (causing hypoxic regions in the Gulf). Education majors sometimes described decisions about their own behavior as well as others' behaviors (Table 7).

The Native students all spoke about the community's approach to a dilemma, which was not necessarily identified in the 4-year college student cohorts. It was most common for Native students to discuss the importance of civil discourse and community education.

> One things [sic] you could do about the company's actions would be to investigate the company that you feel is not coming up to snuff. You can have a say or at least awake people up and show them what these people are doing. If they are doing wrong then it is your duty to come forward with the information that other people do not have...I think that a person might try to resolve this dilemma by giving the knowledge that they learned threw this article to all of the people they know. I think by spreading the word on how bad things could turn out when trying to change something about Mother Earth, would help change others points of view on the subject.

One Native student, however, expressed his concern that others should help solve ecological dilemmas. Unlike the common sentiment at the 4-year college that government regulators should reduce nitrogen run-off, this Native student wrote, 'these scientists should start thinking of ways to reverse things they are doing to our environment. They kill it, they should fix it.' We found that this narrative was exceptional for the tribal college students because this student blamed 'others', who in this case referred to scientists and not farmers.

Discussion and implications

In their influential book, Bereiter and Scardamalia (1987) found that students need opportunities to refine their ideas as they organize, revise, and edit their writing. Our model supports this proposition. Thirty-three percent of the participants in our study moved towards greater ecological literacy after participating in our WTL activities. We argue that the iterative writing process in our study allowed students to work through and develop their understanding of environmental hypoxia, its causes and effects, and the importance to ecosystems (which include humans).

Writing about attitudes and beliefs

Science educators must recognize students' affective responses to concepts in order to help them work towards becoming better decision-makers (Uno and Bybee 1994; National Research Council 1996). However, many students in science classes have only been exposed to the laboratory report genre for which they are told to be objective (Hand, Wallace, and Yang 2004; Mackenzie and Gardener 2006). Subsequently, students are not used to writing about their feelings in a science class, so we were not surprised that many students in both the biology and education cohorts initially wrote as *objective* writers.

Others have demonstrated the importance of emotions as students make meaning of scientific concepts (Levin and Wagner 2006; Littledyke 2008). Thompson and

Mintzes (2002) reported that there was a positive relationship between attitudes and conceptual knowledge in four age groups of participants (children to adults) learning about marine vertebrates. They suggest that science educators who integrate conservation issues into their courses should consider that with increased knowledge students tend to demonstrate increased positive attitudes towards marine animals. Wickman and Ostman (2001) also recognized the relationship between knowledge and emotions. They proposed a theoretical lens to study meaning making that assumes that learning occurs in social contexts when learners draw on both their cognitive and emotional understanding during classroom interactions. Likewise, we found that students needed to draw on both personal and cognitive funds of knowledge if they were able to demonstrate how they made meaning of ecological concepts in their essays about the ecological dilemmas that arise from the phenomenon of hypoxia.

Ecological worldview will undoubtedly reflect what issues elicit emotional responses from students (Snively and Corsiglia 2001). Native American scholars describe the perception that the natural world is one that humans must help keep in balance that many Native people espouse (Cajete 2000; Nelson-Barber and Estrin 1995). Our findings corroborate with this assertion, as the tribal college students were more likely to discuss trade-offs between quality of life and ecological consequences, unlike their mainly Euro-American peers at the 4-year college, who were more focused on economic dilemmas. We recognize that the reservation on which the tribal college is located is economically depressed and experiences very high unemployment. The lack of well-paying jobs likely contributes to the worldview differences of the populations of students at the two research sites. This study, nonetheless, highlights that context (student worldviews, geographic location, economic context) will all likely affect how students write about ecological issues, dilemmas, and decisions to resolve these dilemmas, and the attitudes and emotions that they convey in their writing.

Guiding writing

Because writing is a powerful exercise that enables students to reflect on what they know and what they think they know, writing prompts can encourage them to consider issues more deeply than they might have without guidance. If writing prompts are well designed (provide an authentic purpose for writing, motivate students to want to write, and help students structure their writing), then educators can expect focused written products (Turner and Broemmel 2006). Calfee and Miller (2005) described a structured writing prompt to be one that gives the writer necessary background information (topic, audience, purpose, genre), as well as guides students on the process of writing (planning, editing, finalizing a draft). We argue that our prompts followed these criteria, yet we suggest that the lower success rate of students moving towards authentic category of ecological literacy than our previous study can be attributed to less scaffolding that we, as educators, provided to students during the WTL study. Students needed more guidance on active reading and discussions on how to connect conceptual understanding with potential decisions to resolve dilemmas.

Guidance can be provided not only in the form of writing prompts, but also in how educators foster in-class discussions. Flower et al. (1990) recognized that the task of extracting information from reading to writing in one's own words is a complex process. Because this step is so significant in reading-to-write activities, the lack of classroom discussion about the reading explains why fewer students in this study (compared to our previous study) were classified as *authentic* writers. Rivard and Straw (2000) found that Francophone Canadian middle school students, who were given opportunities to talk about ecology with their peers and teachers before engaging in writing assignments, demonstrated a stronger content understanding compared to students who were not given opportunities to talk before writing. Students were able to clarify their knowledge through discussion, and writing allowed them to integrate new knowledge with prior knowledge. We recognize that our students would have benefitted from more structured in-class discussion about the ecological dilemmas that they identified before they wrote their final essays, and in a subsequent study we have explored the role of instructor-guided discussions.

Implications: making decisions to resolve dilemmas

Most of the college students in this study recognized the competing economic, ecological, and cultural consequences of any decisions that they might make to resolve their ecological dilemmas. However, if we want college students to be more engaged in social issues and dilemmas related to world population growth, have broader worldviews, and initiate changes in personal habits related to environmental sustainability and make ecologically literate decisions (Jimenez-Aleixandre and Pereiro-Munoz 2002; Davidson 2003), then science educators need to allow students the opportunities to consider pros and cons of decisions. Guided expressive writing allows learners to consider what they know, how they feel about it, trade-offs for any decisions that they make and the difficulty in resolving their (potentially) competing ecological, economic, and cultural worldviews.

By giving students a heuristic or guide that they can follow when faced with an ecological dilemma long after they graduate from college, we believe they will be more prepared to be environmental stewards and decision-makers. Meyer and Munson (2005, 6) suggested that expressive writing strengthens the resolve of writers to act by personalizing information; they stated, ‘creative thinking can empower students to act.’ We know that reading and writing allows students to learn and retain concepts, theories, and model more than students who are not engaged in these activities (Shanahan 2004). We also know that through discursive interaction with the environment, people are able to understand their world and attach meaning to their behaviors (Bronckart 1995). Hence, by allowing students to draw on both their affective and cognitive funds of knowledge when learning about ecological concepts educators can help them to become more ecologically literate.

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References

Adeniyi, E.O. 1985. Misconceptions of selected ecological concepts held by some Nigerian students. *Journal of Biological Education* 19, no. 4: 311–46.

Aikenhead, G.S. 1997. Toward a First Nations cross-cultural science and technology curriculum. *Science Education* 81: 217–38.

Balgopal, M.M., and L.M. Montplaisir. 2011. Meaning making: What reflective essays reveal about biology students' ideas about natural selection. *Instructional Science* 39, no. 2: 137–69.

Balgopal, M.M., and A.M. Wallace. 2009. Decisions and dilemmas: Using writing to learn activities to increase ecological literacy. *Journal of Environmental Education* 40, no. 3: 13–26.

Barrett, G.W. 2001. Closing the ecological cycle: The emergence of the integrative cycle. *Ecosystem Health* 7, no. 2: 79–84.

Bereiter, C., and M. Scardamalia. 1987. *Psychology of written composition*. Hillsdale, NY: Lawrence Erlbaum.

Berkowitz, A.R. 2007. Towards a definition of ecological literacy. http://www.ecostudies.org/people)sci_berkowitz_literacy.html (accessed May 8, 2007).

Berkowitz, A.R., M.E. Ford, and C.A. Brewer. 2005. A framework for integrating ecological literacy, civics literacy, and environmental citizenship in environmental education. In *Environmental education and advocacy,* ed. E.A. Johnson and M.J. Mappin, 227–66. Cambridge: Cambridge University Press.

Bowers, C.A. 2001. How language limits our understanding of environmental education. *Environmental Education Research* 7, no. 2: 141–51.

Bransford, J.D., A.L. Brown, and R.R. Cocking. 2000. *How people learn: Brain, mind, experience and school*. Washington, DC: National Academy Press.

Bright, C. 1999. The nemesis effect. *World Watch* 12: 12–23.

Bronckart, J.-P. 1995. Theories of action and speech. In *Sociocultural studies of the mind*, ed. J.V. Wertsch, P. Del Rio, and A. Alvarez, 75–91. Cambridge: Cambridge University Press.

Bruyere, B.L. 2008. The effect of environmental education on the ecological literacy of first-year college students. *Journal of Natural Resources & Life Science Education* 37: 20–6.

Cajete, G. 2000. *Native science: Natural laws of interdependence*. Santa Fe, NM: Clear Light.

Calfee, R.C., and R.G. Miller. 2005. Breaking ground: Constructing authentic reading-writing assessments for secondary school students. In *Learning to write and writing to learn: Theory and research in practice*, ed. R. Indrisano and J. Paratore, 203–20. Newark, DE: International Reading Association.

Cherrett, J.M. 1989. Key concepts: The results of a survey of our members' opinions. In *Ecological concepts*, ed. J.M. Cherrett, 1–6. Oxford: Blackwell.

Cutter-Mackenzie, A., and R. Smith. 2003. Ecological literacy: The "missing paradigm" in environmental education. *Environmental Education Research* 9, no. 4: 497–524.

D'Avanzo, C. 2003. Application of research on learning to college teaching: Ecological examples. *Bioscience* 53, no. 11: 1121–8.

Davidson, J. 2003. Citizenship and sustainability in dependent island communities: The case of the Huon Valley region in southern Tasmania. *Local Environment* 8, no. 5: 527–40.

Diaz, R.J. 2001. Overview of hypoxia around the world. *Journal of Environmental Quality* 30: 275–81.

Diaz, R.J., and R. Rosenberg. 2008. Spreading dead zones and consequences for marine ecosystems. *Science* 321, no. 5891: 926–9.

Dlugokienski, A., and V. Sampson. 2008. Learning to write and writing to learn in science. *Science Scope* 34, no. 3: 14–9.

Flower, L., V. Stein, J. Ackerman, M.J. Kantz, and K. McCormick. 1990. *Reading-to-write: Exploring a cognitive and social process*. New York: Oxford University Press.
Grace, M.M., and M. Ratcliffe. 2002. The science and values young people draw upon to make decisions about biological conservation issues. *International Journal of Science Education* 24, no. 11: 1157–69.
Hamilton-Ekeke, J.-T. 2007. Relative effectiveness of expository and field trip methods of teacher on students' achievement in ecology. *International Journal of Science Education* 29, no. 15: 1869–89.
Hand, B., L. Hohenshell, and V. Prain. 2004. Exploring students' responses to conceptual questions when engaged with writing experiences: A study with year 10 science students. *Journal of Research in Science Teaching* 41: 186–210.
Hand, B., C. Wallace, and E.-M. Yang. 2004. Using a science writing heuristic to enhance learning outcomes from laboratory activities in seventh-grade science: Quantitative and qualitative aspects. *International Journal of Science Education* 26, no. 2: 131–149.
Hellden, G.F. 2004. A study of recurring core developmental features in students' conceptions of some key ecological processes. *Canadian Journal of Science, Mathematics and Technology Education* 4, no. 1: 59–76.
Jimenez-Aleixandre, M.-P., and C. Pereiro-Munoz. 2002. Knowledge producers or knowledge consumers? Argumentation and decision making about environmental management. *International Journal of Science Education* 24, no. 11: 1171–90.
Jordan, R., F. Singer, J. Vaughan, and A. Berkowitz. 2009. What should every citizen know about ecology? *Frontiers in Ecology and the Environment* 7, no. 9: 495–500.
Keys, C.W. 1999. Revitalizing instruction in scientific genres: Connecting knowledge production with writing to learn in science. *Science Education* 83: 115–30.
Lawson, A.E., S. Alkhoury, R. Benford, B.R. Clark, and K.A. Falconer. 2000. What kinds of scientific concepts exist? Concept construction and intellectual development in college biology. *Journal of Research in Science Teaching* 37, no. 9: 996–1018.
Leach, J., R. Driver, P. Scott, and C. Wood-Robinson. 1996. Children's ideas about ecology 2. Ideas found in children age 5–16 about the cycling of matter. *International Journal of Science Education* 18: 19–34.
Levin, T., and T. Wagner. 2006. In their own words: Understanding student conceptions of writing through their spontaneous metaphors in the science classroom. *Instructional Science* 34, no. 3: 227–78.
Littledyke, M. 2008. Science and environmental education: Approaches to integrating cognitive and affective domains. *Environmental Education Research* 14, no. 1: 1–7.
Liu, X. 2004. Using concept mapping for assessing and promoting relational conceptual change in science. *Science Education* 88: 373–96.
Mackenzie, A., and A. Gardener. 2006. Beyond the lab report: Why we must encourage more writing in biology. *The American Biology Teacher* 68, no. 6: 325–7.
Magntorn, O., and G. Hellden. 2005. Student–teachers' ability to read nature: Reflections on their own learning in ecology. *International Journal of Science Education* 27, no. 10: 1229–54.
Magntorn, O., and G. Hellden. 2007. Reading new environments: Students' ability to generalize their understanding between different ecosystems. *International Journal of Science Education* 29, no. 1: 67–100.
Mason, L. 1998. Sharing cognition to construct scientific knowledge in school context: The role of oral and written discourse. *Instructional Science* 26: 359–98.
Meyer, N.J., and B.H. Munson. 2005. Personalizing and empowering environmental education through expressive writing. *Journal of Environmental Education* 36, no. 3: 6–14.
Munson, B.H. 1994. Ecological misconceptions. *Journal of Environmental Education* 25: 30–5.
National Research Council. 1996. *National science education standards*. Washington, DC: National Academy Press.
Nelson-Barber, S., and E.T. Estrin. 1995. Bringing Native American perspectives to mathematics and science teaching. *Theory Into Practice* 34, no. 3: 174–85.
Norris, S.P., and L.M. Phillips. 2003. How literacy in its fundamental sense is central to scientific literacy. *Science Education* 87: 224–40.

North, S. 2005. Different values, different skills? A comparison of essay writing by students from arts and science backgrounds. *Studies in Higher Education* 30, no. 5: 517–33.
Orr, D.W. 1992. *Ecological literacy: Education and the transition to a postmodern world*. Albany, NY: State University of New York Press.
Prain, V. 2006. Learning from writing in secondary science: Some theoretical and practical implications. *International Journal of Science Education* 28, no. 2–3: 179–201.
Raloff, J. 2004. Dead waters: Massive oxygen-starved zones are developing along the world's coasts. *Science News* 165, no. 23: 360–2.
Raloff, J. 2004. Limiting dead zones: How to curb river pollution and save the Gulf of Mexico. *Science News* 165, no. 24: 378–80.
Ritchie, S., D. Rigano, and A. Duane. 2008. Writing an ecological mystery in class: Merging genres and learning science. *International Journal of Science Education* 30, no. 2: 143–66.
Rivard, L.P. 2004. Are language based activities in science effective for all students, including low achievers? *Science Education* 88: 420–42.
Rivard, L.P., and S.B. Straw. 2000. The effect of talk and writing on learning science: An exploratory study. *Science Education* 84: 566–93.
Roth, C.E. 1990. Environmental literacy: Its roots, evolution and direction in the 1990s. Columbus, OH: Clearinghouse for Science Mathematics and Environmental Education. (ERIC Document Reproduction Service No. ED348235).
Saul, E.W. 2004. *Crossing borders in literacy and science instruction: Perspectives on theory and practice*. Newark, DE: International Reading Association.
Schneider, S.H. 1997. Defining and teaching environmental literacy. *Trends in Ecology and Evolution* 12, no. 11: 457.
Shanahan, C. 2004. Better textbooks, better readers and writers. In *Crossing borders in literacy and science instruction*, ed. E.W. Saul, 370–82. Newark, DE: International Reading Association.
Slingsby, D. 2001. Perceptions of ecology: Bridging the gap between academia and public through education and communication. *Bulletin of Ecological Society of America* 82, no. 2: 142–8.
Slobodkin, L.B. 2003. *A citizen's guide to ecology*. New York, NY: Oxford University Press.
Snively, G., and J. Corsiglia. 2001. Rediscovering indigenous science: Implications for science education. *Science education* 85: 6–34.
Stamp, N. 2005. Overcoming ecological misconceptions self-test. Using the power of story. http://ecomisconceptions.binghamton.edu/selftest.htm (accessed August 22, 2009).
Stone, M.K., and Z. Barlow. 2005. *Ecological literacy: Educating our children for a sustainable world*. San Francisco, CA: Sierra Club Books.
Thompson, T.L., and J.J. Mintzes. 2002. Cognitive structure and the affective domain: On knowing and feeling in biology. *International Journal of Science Education* 24, no. 6: 645–60.
Turner, T., and A. Broemmel. 2006. 14 writing strategies. *Science Scope* 30, no. 4: 27–31.
Uno, G.E., and R.W. Bybee. 1994. Understanding dimensions of biological literacy. *Biosciences* 44, no. 8: 553–7.
Van Eijck, M., and W.-M. Roth. 2007. Keeping the local local: Recalibrating the status of science and traditional ecological knowledge (TEK) in education. *Science Education* 91: 926–47.
Wallace, C. 2004. Framing new research in science literacy and language use: Authenticity, multiple discourses, and the "Third Space". *Science Education* 88: 901–14.
Walshe, N. 2008. Understanding students' conceptions of sustainability. *Environmental Education Research* 14, no. 5: 537–58.
Wickman, P.-O., and L. Ostman. 2001. Learning as discourse change: A sociocultural mechanism. *Science Education* 86: 601–23.
Wilkinson, L.C., and E.R. Silliman. 2000. Classroom language and literacy learning. In *Handbook of reading research, volume 3*, ed. M.L. Kamil, P.D. Pearson, R. Barr, and P. B. Mosenthal, 337–60. Mahwah, NJ: Lawrence Erlbaum.

Appendix 1. Writing assignment directions for 4-year college students

Background

Every day there are dozens of stories and reports in the news that have to do with biology. There are increasing calls from scientists and policy makers for the general public to become better able to read and understand these current issues so that sound decisions and policies can be made. As a future biologist, you are especially important to this process because you are not only a participating member of our society, but will also be a professional with expertise that can help interpret science to non-scientists.

The articles

As you may have guessed from your pre-assessment, the articles you will read are about hypoxia!

(1) Please actively read the two articles (with pen in hand to question, comment, and emphasize aspects of your choosing in each of these articles). Use the third article (the Hypoxia Fact Sheet) as a reference to help you understand the first two articles.
(2) When you are finished, find another person with whom to discuss the articles (either in or outside of class) using the following questions as guidelines for your discussion:
  (a) What did you already know about this issue?
  (b) What didn't you know about this issue?
  (c) Can you summarize how hypoxia occurs starting with nutrients and ending with low oxygen levels?
  (d) Which types of organisms are involved?
  (e) What are the probable causes?
  (f) What are potential solutions?

The essays

(1) Each of these essays will probably be about 1 page in length, but longer or shorter is fine.
(2) Please type all three essays on separate pages, labeling each with:
  (a) Your name.
  (b) The essay number (#1, #2, or #3)
(3) Do not worry if you feel as though you are repeating yourself in the three essays. Each essay should be able to stand 'on its own' and not refer to prior essays, but should have a different 'feel' to the writing.
(4) You will earn 10 points per essay for following directions and submitting on time.

Essay #1: Identify with being a (1) Midwestern farmer, (2) Midwestern homeowner, or (3) a Gulf of Mexico fisherman, and write an article to a fictitious newsletter explaining hypoxia in order to educate your specific community about this issue.

Essay #2: Identify with the same person that you did in the first essay and write a blog entry that explores how that person may feel about the hypoxia issue.

Essay #3: Identify with the same person that you did in the first essay and write out an imagined conversation between yourself and this person that describes (1) a dilemma they may experience regarding decisions they may be faced with pertaining to the hypoxia issue and (2) a dilemma that you may experience regarding decisions you may be faced with pertaining to the hypoxia issue. Make sure to include what additional information is needed to address these dilemmas and to also predict whether they can be resolved or not.

Appendix 2. Writing assignment directions for tribal community college students

You will read an article and write three essays relating to the reading. Each essay is worth 10 points, which will be awarded if you complete the assignment, follow the directions, and submit your work on time.

Writing assignment I

(1) Compose an essay during class in which you include the following:

   (a) Identify and describe ecological concepts you noticed in the reading assignment.
   (b) Provide an example for each concept you identified and describe how they illustrate the concept and help you better understand them.

(2) Use your article as reference as you compose your essay. You may wish to underline, circle, or otherwise identify key points in the articles if you have done so already. You may find a classmate with whom to discuss your ideas either in or outside of class.
(3) Please type your essay! Make sure that you have time to type your essay in class or at home. Do not forget to put your name and the date on each page of your essay.
(4) Hand in your typed essay.

Writing assignment II

(1) Add the following components to your essay during class (or at home):

   (a) Describe how you feel about the story that is communicated in the reading.
   (b) Describe how other members of society may feel about the story that is communicated in the reading.

(2) Please type your essay. Make sure that you have had time to type your revised essay. Do not forget to put your name and date on each page of your essay.
(3) Hand in your typed essay.

Writing assignment III

(1) Add the following components to your essay during class (or at home):

   (a) Identify at least one dilemma that a member of society may experience after reading the article.
   (b) Imagine how this person may resolve the dilemma and describe this.
   (c) Explain whether you identify with this dilemma or not and why.
   (d) Describe how you could/would address this dilemma.

(2) Please type your essay. Make sure that you have had time to type your revised essay. Do not forget to put your name and date on each page of your essay.
(3) Hand in your typed essay.