Decisions and Dilemmas: Using Writing to Learn Activities to Increase Ecological Literacy

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ABSTRACT: Researchers tested whether writing increases ecological literacy in undergraduate elementary education students. The authors asked students to write 3 guided essays addressing the cognitive, affective, and behavioral domains in response to news articles on hypoxia. Of the 22 students, 64% improved their ecological literacy from the 1st essay to the 3rd essay. The authors conclude that writing can be an effective learning tool for increasing ecological literacy. They also posit that ecological literacy is a continuum and not a discrete state. Authentic learners who can recognize dilemmas and potential decisions (and their ecological consequences) are on one end of this continuum.

KEYWORDS: ecological literacy, learning, preservice teachers, writing

A consensus in the institution of U.S. education acknowledges that U.S. science educators need to increase scientific literacy of kindergarten through 12th grade (K–12) and college students (Futuyma, 2007). The National Research Council (NRC) defined *science literacy* as "the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity" (NRC, 1996, p. 22). Uno and Bybee (1994) developed a framework that outlines specific levels of scientific literacy: At a nominal level, a learner can recognize scientific terms. At a functional level, a learner can apply scientific terms. At a structural level, a learner demonstrates procedural knowledge by transferring concepts and describing them in his or her own words. Last, at a multidimensional level, a learner can examine socioscientific issues and make decisions on the basis of his or her scientific understanding.

Slavin (2003) identified three domains of learning: cognitive, affective, and behavioral. Researchers have long recognized that meaningful learning experiences draw on all three domains (Bransford,

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Brown, & Cocking, 2000; Sousa, 2001). *Meaningful learning experiences* are those that relate to an individual's life (past, present, or future). A person who achieves a multidimensional level of scientific literacy will be able to find connections among his or her conceptual understanding (using cognitive domain), attitudes and beliefs (using affective domain), and personal decision making (using behavioral domain; Liem, 2005; Uno & Bybee, 1994). When an individual draws on both his or her cognitive and social awareness, that person is then labeled an *authentic learner* (Bransford et al., 2000; Oers & Wardekker, 1999). Authentic, scientifically literate learners can subsequently transfer and apply concepts to new examples:

> Successful learning within this context will mean, then, that [the learner] is using scientific language to communicate about personally meaningful science events. When [the learner] needs to use scientific language to express her own experiences, she will be authentically communicating. The authentic use of language will involve the appropriation of academic discourse into everyday language. (Wallace, Hand, & Yang, 2004, p. 903)

Some scientists have argued that Americans are not only scientifically but also ecologically illiterate (Barrett, 2001; Orr, 1992; Stamp, 2005). Although ecologists and science education researchers have recently held discussions regarding a salient measure of ecological literacy, the two disciplines have not necessarily reached a consensus on how to measure ecological literacy. We believe the current research climate is open to interdisciplinary discussion, as evidenced this past year by the ecology and environmental education strands at conferences of the Ecological Society of America and the National Association of Researchers in Science Teaching. Although we were unable to find a consistently used instrument to measure ecological literacy, we found numerous references identifying ecological misconceptions in students from elementary to undergraduate levels across the globe (e.g., Adeniyi, 1985; Leach, Driver, Scott, & Wood-Robinson, 1996; Munson, 1994; Stamp). These misconceptions relate to a wide range of concepts regarding ecosystems interactions, food chain or food webs, evolutionary adaptations, carrying capacity or population growth, and the niche concept.

What is ecological literacy?

Ecological literacy refers to a student's understanding not only of ecological concepts, but also of his or her place in the ecosystem. This broad definition captures the essence of both ecological and environmental awareness. Roth (1992) first introduced the term *environmental literacy*; however, the term *ecological literacy*, championed by Orr (1989, 1992), has replaced it (Cutter-MacKenzie & Smith, 2003; Roth, 1992). Also, van Weelie (2002) explained that to be environmentally aware, a person must understand the relevant scientific concepts and make decisions on the basis of that understanding, and this definition is similar to that of ecological literacy. The concept of sustainability is pivotal to literacy because it links many of the ecological concepts (Bybee, 1993; Orr, 1992; Stone & Barlow, 2005). Orr (1992) suggested that when individuals understand broad ecological concepts (e.g., food webs, trophic levels, limiting resources, and population dynamics), they are likely able to step back and consider their own place in the ecosystem. Berkowitz (2007) used another term, *ecological thinking*, which combines ecological understanding and environmental awareness. In addition, an ecologically literate individual demonstrates multidimensional literacy when making decisions about behavior on the basis of an understanding of ecological concepts (Uno & Bybee, 1994). In the present article, we suggest that if a student is ecologically literate, he or she can understand the concept of interrelatedness and is more likely to transfer that knowledge to broader environmental and conservation topics, such as world population growth, global warming, and pollution. After a thorough review of the literature, we formulated our own definition for this study: An *ecologically* *literate person* can recognize the relevance and application of ecological concepts to understanding human impacts on ecosystems.

Why do we need an ecologically literate public?

Many ecology educators have argued that media reports dictate current public understanding of ecological principles and subsequent decision making (Bowers, 1996; Louv, 2006; Orr, 1992; Slingsby, 2001; Stone & Barlow, 2005). College instructors, through their classroom activities and assessments, can identify students' misconceptions and confusion about ecology. Instructors have the opportunity to respond to such confusion and help to increase the ecological literacy of their students. Orr (1992) implored university faculty members to integrate the concept of ecological literacy into their curricula to help transform young adults' understanding of current and future ecological crises. In an age of increasing societal awareness of global climate change, air and water pollution, and world population growth, it becomes imperative for college educators to foster ecological literacy in their students (Bybee, 1993; Stone & Barlow). The broad impact of increasing ecological literacy among young adults is, hopefully, that they will engage more in issues and dilemmas related to world population growth, develop broader worldviews, initiate changes in personal habits related to environmental sustainability, and make ecologically literate decisions (Brody, 2002; Davidson, 2003; Jimenez-Aleixandre; 2002). In recognition of the importance of promoting ecological literacy, our goal in the present study was to examine how guided writing activities could increase ecological literacy in elementary education majors.

To improve college science teaching of ecology, we developed an original model (Figure 1). We based the Cognitive-Affective-Behavior (CAB) Writing to Learn (WTL) model on the premise

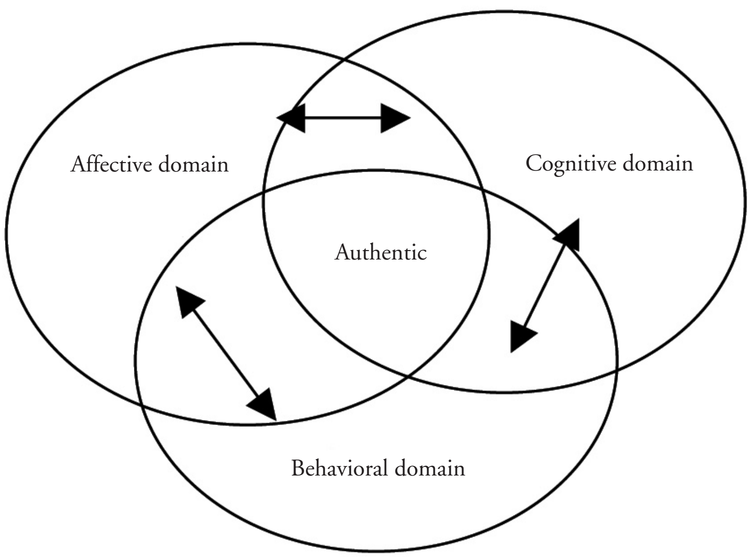

FIGURE 1. Cognitive-Affective-Behavior Writing to Learn model. Students who demonstrate all three domains are considered authentic learners. Authentic learners can not only identify relevant dilemmas but also appreciate how their understanding of a scientific concept can influence their decisions.

that ecologically literate citizens must identify and resolve ecological dilemmas (e.g., knowing that burning fossil fuels creates pollution though it allows convenient transportation). For students to identify a dilemma, they must understand the relevant concepts, recognize personal and societal connections involving ecological phenomena, and acknowledge decisions about behaviors that would resolve the dilemma.

We designed a teaching heuristic using the CAB-WTL model that outlines strategies for science instructors to foster authentic learning. The proposed guided writing activities require that students read a current news article regarding a provocative ecological issue and then write three separate iterations of brief in-class essays. The instructor provided probing questions and prompts that elicited the cognitive, affective, and behavioral domains of learning. Because writing is a reflective exercise, we posited that guided writing would enable learners to examine their prior knowledge and increase their understanding of ecological concepts. By the third essay, students are asked to identify a personal dilemma relevant to the issue; thus, they are given the opportunity to demonstrate ecological literacy in their written discourse.

Ecological Misconceptions

Scholars have conducted little research on effective methods of addressing ecological misconceptions. D'Avanzo (2003) reported in her analysis of articles that were published over a 6-year period (1997–2002) in the *Journal of Research Science Teaching* that only 7 of 89 research articles in five disciplines (physics, chemistry, biology, geology, and ecology) focused on ecological understanding by students. Of those seven articles on ecology research, all were conducted in the K–12 setting (D'Avanzo). In the present study, we found that few researchers have focused on ecological understanding at the college level, even though there has been a call for research in this area (Bybee, 1993). Despite the acknowledgment that K–12 and college students have misconceptions about ecological principles, researchers have published little on how to resolve ecological misconceptions.

Identifying and Resolving Misconceptions

Instructors and students can use concept maps to identify misconceptions (Jones, Carter, & Rua, 2000; Novak & Gowin, 1984). When constructing concept maps, students are asked to make associations among several of the terms they have generated in response to a central term (e.g., ecology) and subsequently to label the connecting lines or links between each pair of the terms. When students struggle with associated terms, they may end up constructing limited concept maps. When students can generate related terms but are unable to describe the exact relationship of those terms, they may leave their links unlabelled or reveal their misconceptions through inaccurate links. When students are asked to generate their own open-ended concept maps, their prior knowledge and experiences emerge (Jones et al.). Researchers can analyze concept maps quantitatively and qualitatively (Kinchin, Hay, & Adams, 2000). Although concept maps enable useful assessment of students' conceptual understanding, they do not necessarily capture the affective and behavioral connections that written discourse exposes (Liu, 2004).

Grace and Ratcliffe (2002) found that learning about environmental and ecological concepts is tightly associated with affective learning and with value and belief systems. Educating people to be ecologically literate involves both cognitive and affective domains (Grace & Ratcliffe). Stamp (2005) suggested the use of storytelling as a way of engaging students. She found that student interest was higher during subsequent inquiry activities using the Engage–Explore–Explain–Elaborate–Evaluate (5E) learning cycle. The Biological Sciences Curriculum Study developed the 5E model (NRC, 1996) as a guide for science teachers to develop inquiry activities. By following this instructional model, teachers help students become engaged in an activity, which allows them to explore specific concepts. Students then explain, elaborate, and evaluate concepts, in small or large groups, during the learning process. Case and Fraser (1999) concluded that chemical engineering students needed more than extra instruction on topics; they needed tangible objects and thought experiments to promote positive conceptual change. Resolution of misconceptions also depends on the types of misconceptions that are being targeted. Yeung and Law (2001) and Case and Fraser discovered that their students resolved their own misconceptions when they were challenged to think about global concepts and not just localized issues.

Writing to Promote Learning

Writing allows educators and researchers to identify weak links in conceptual understanding while enabling writers to disclose personal connections they have made to the subject matter (Balgopal, 2007). Rivard and Straw (2000) and Rivard (2004) argued that instructors have not fully used language-based learning activities to promote learning in the sciences, even though they have recognized that reading and writing activities can help students to acquire new knowledge, and to help clarify and connect scientific ideas (Mason, 1998; Saul, 2004; Wallaceet al., 2004). The activity of writing to learn has been an area of interest not only to education researchers, but also to practitioners who seek a variety of assessment tools to evaluate the diverse learning styles of students (Hand & Prain, 2004; Mason; Wallace et al., 2004). Students exhibit multiple learning strategies, including those depending on visual, auditory, or kinesthetic skills (Slavin, 2003). Hand and Prain found that as writing experiences increase, so do conceptual-understanding and multiple-choice test scores. Although multiple-choice tests alone do not give teachers insight into whether learners can use concepts (Mintzes, Wandersee, & Novak, 2000), Hand and Prain's findings highlight how written discourse serves as an assessment tool and learning strategy.

Reflective activities requiring students to stand back from their subject matter and think about it, such as expressive writing, encourage students to be critical of their own understanding (D'Avanzo, 2003). Expressive writing is a style that resembles how people communicate in everyday speech, as it conveys or reflects on information and sometimes allows writers to connect prior conceptions to new conceptions (Keys, 1999). In turn, students who are more metacognitive, or aware of their own learning and limitations, are most likely to be actively involved in their own learning process by addressing their confusion (Balgopal, 2007; D'Avanzo; Mason, 1998). Bereiter and Scardamalia (1987) pointed out that reflection, during which the writer must modify his or her thoughts to accommodate changes in the composition, is critical for meaningful learning.

Assessing Learning Through Written Discourse

Sousa (2001) described learning as the interface between two continua: sense and meaning. As students make sense of a concept (find it plausible) and as they find meaning in the concept (find personal relevance), they are more likely to commit the concepts learned to long-term memory. Balgopal (2007) found that college biology essays could be categorized by how students described scientific concepts (Table 1). When students made only personal reflections on lectures and reading passages, Balgopal classified them as subjective learners. When students described concepts by drawing on examples from other science courses or readings, Balgopal (2007) classified them as objective learners. Authentic learners were able to do both by describing the scientific concept in a personally meaningful way that also demonstrated their scientific understanding of the topic. Authentic learners could also transfer their understanding of a concept to another example, regardless of whether it was from class or personal experience. In addition, authentic learners were more motivated than were subjective or objective learners to resolve their misconceptions (Balgopal). Superficial (or detached) learners could not draw on personal or conceptual examples to explain the reading or lecture, providing no evidence that it made sense or was meaningful to them.

TABLE 1. Cognitive and Affective Affiliation Model of Learning

Variable	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. Superficial students can find few affective or cognitive connections; authentic students find both and integrate them effectively.

Guided Writing

Constructivist teaching strategies can be effective in helping students to identify and resolve their misconceptions, as well as to enhance their retention of concepts (Mintzes et al., 2000). Constructivist teachers, those who allow students to construct their understanding on prior knowledge, can scaffold learning through prompts and class discussion (Bransford et al., 2000; NRC, 1998). Effective teachers use many strategies to engage students. For example, teachers have found inquiry laboratory exercises useful because they often allow students to initially recall their own understanding before requiring them to use all three domains of learning (cognitive, affective, and behavioral). In this manner, students can often make sense of the activity and remember the concepts (Bransford et al.; Sousa, 2001). Likewise, writing activities are consistent with constructivist methods because they allow students to identify their own ideas before the students are asked to delve further into a topic (Keys, 1999; Mason, 1998; Rivard, 2004; Shanahan, 2004). Carlson (2007) explained, “Ultimately, teaching students to write scientifically is teaching them to think scientifically” (p. 53). Although several activities have been discussed in the literature for engaging students in their own learning process, researchers have published little on the role of guided writing activities as a way of increasing ecological thinking and understanding.

The CAB-WTL model incorporates three different but interrelated domains (Figure 1), whereas most science courses and assignments focus exclusively on the cognitive domain. Students find meaning in concepts by making either cognitive or affective connections (Balgopal, 2007). As a result, we developed a model on the basis of the assumption that when the instructor addresses all domains of learning, there is a higher probability of authentic learning among class members with diverse learning styles. Traditional teaching methods usually start (and end) with the cognitive domain, but we posit that not all students start at the same learning point: They start at various learning points depending on their prior learning experiences, expectations of a subject, and expectations of their own abilities.

Methods

We used a mixed-methods approach, focusing on the role of guided writing on the development of ecological literacy of undergraduate learners. Through empirical and qualitative analyses, we tested our prediction that guided writing activities using the CAB-WTL model would increase ecological literacy.

Population of Learners

Participants were 24 elementary education majors (5 men, 19 women) from a mid-size normal university in the Midwest. All students were European Americans. Researchers reported that many elementary pre- and in-service teachers are unable to connect ecological conceptual understanding with teaching about personal decision making (Cutter-Mackenzie & Smith, 2003; Ekborg, 2005; Hart, 2002; Summers, Kruger, Childs, & Mant, 2001). Therefore, we were interested in studying how this population of learners would perform in our study.

Setting

The study was conducted in a nonmajors' biology course, Exploring Biology—a required course designed, specifically for elementary education majors, around three main units (organismal biology, ecological interactions, and genetics and evolutionary processes). The instructor, Alison Wallace, used an inquiry-based constructivist approach to teaching and encouraged cooperative group work and discussion. The main objective of this course was to introduce students to the nature of scientific inquiry in the context of basic life-science concepts. The instructor incorporated field trips to natural areas and preserves and offered hands-on activities during combined lecture and laboratory class times.

Study Design and Data Collected

We collected two types of data during this study: three concept maps and three two-page in-class essays. We used the concept maps to identify misconceptions and explore changes in the complexity and interconnectedness of student thinking about ecological concepts before and after the implementation of the CAB-WTL model. For all three guided writing essays, students responded to an article about a current ecological issue. We elicited student writing from the three learning domains: cognitive, affective, and behavioral.

Students first created a preassessment concept map around the word *ecology*. Then they went through regular instruction of an ecology unit and, on completion of the unit, constructed a second concept map. We then gave students three related short articles that focused on hypoxia in the Gulf of Mexico (Raloff, 2004a, 2004b) and asked them to write the three CAB-WTL essays during three separate class periods, with written and verbal guidance provided (see the Appendix for the actual assignments). Each student created a final concept map after the third essay. We did not ask students to write a fourth in-class essay. However, in retrospect, we believe the true test of guided writing activities and ecological literacy gains would be to assess how well students could transfer the cognitive, affective, and behavioral skills, which we modeled during the first three in-class essays, to a related but separate topic.

Data Analysis

Concept Maps

Each of the three concept maps were originally scored for the following: (a) shape of map—chain, spoke, or networked (Kinchin et al., 2000); (b) number of items listed; (c) number of ecological concepts identified; (d) number of examples to support concepts; (e) number of correctly labeled links; (f) number of unlabelled links; and (g) any mention of personal professional identity (e.g., educator, ecologist, teacher). However, due to the high degree of variation among the students' maps, we decided to create a simple index for quantifying each map: the *Concept-to-Item ratio* (C:I), defined as the number of accurately supported ecological concepts as a ratio of the total number of items (not counting the links).

Essays

We both read each essay and then placed it into the following categories on the basis of its levels of depth and sophistication in the cognitive, affective, and behavioral domains (Table 2). We found

TABLE 2. Rubric Used to Categorize Student Essays

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/previous experience
Authentic	Demonstrates and integrates conceptual understanding and personal connections and behaviors relating to the issue in a way that demonstrates ecological literacy

that students sometimes revealed their personal, cultural, or professional affiliations as they discussed dilemmas, so these additional self-identity labels were noted when relevant (Table 3). We scored essays on their accord with scientifically accepted descriptions of ecological concepts (not on syntax and grammar) and assigned each to a literacy level of superficial, objective, subjective, or authentic (Table 4). We both scored all essays and then conferred with one another. Of the 66 essays that we both read, 60 (91%) received identical scores. For essays receiving discrepant scores, we came to a consensus on the basis of our separate interpretations and subsequent discussions.

TABLE 3. Rubric for Identifying Qualitative Components of Students Essays

Self-identity	Characteristics of written discourse
Cultural	Identifies specific ways that he or she understands ecological dilemmas based on cultural perspectives
Professional	Identifies specific ways that students can use their educational training to address the ecological issue

TABLE 4. Changes in Student Literacy Categories From First to Third Essays After Implementing the Cognitive-Affective-Behavior Writing to Learn Model

	Third Essay			
Variable	Superficial	Subjective	Objective	Authentic
First Essay				
Superficial		2		7
Subjective		1		1
Objective			4	4
Authentic				3

Note. The authentic writers are the ones deemed to be ecologically literate. The most notable result is the seven students who moved from superficial to authentic.

Hypoxia Questionnaire

After the students had written their third essay, we administered a brief, short-answer assessment asking them to describe and identify the cause of hypoxia (see the Appendix).

Results

Essays

Of the 22 students who completed all of the assignments, 64% improved their ecological literacy score (Table 5). There were 8 students whose scores did not increase from the first to the third essay. Also, 1 student remained in the subjective category, 4 students remained in the objective category, and 3 students had been categorized as authentic learners since the first essay. By the end of the three guided-writing assignments, 15 of the 22 students (68%) were measured as authentic writers; that is, writers who could describe the ecological concepts and make personal connections to their role in either creating the ecological crises or resolving it. Of the 22 students, 4 remained objective writers, with a firm grasp of the concepts but without the ability to integrate the personal connections necessary for ecological literaacy. In all, 1 student was unable to examine the hypoxia issue from any lens other than the affective domain. In addition, 2 students were able to move from the superficial to subjective domain, showing that they were able to describe personal and societal effects of the hypoxia issue, but they did not display enough conceptual understanding to be deemed ecologically literate. Essay excerpts representing each of the four categories are presented in Table 6.

Concept Maps

Overall, we saw the most dramatic changes between the first and second maps, both of which measured the effects of inquiry-based instruction before the guided writing activities occurred (Table 6). The students who improved the most from the first essays to the third essays also continued to increase their scores from the second maps to third maps, both of which spanned the guided writing activities. In future studies, we will explore this phenomenon by using larger sample sizes to see if this trend holds, and if so, to judge whether it is statistically significant.

Hypoxia Questionnaire

The students whose essay ratings and concept map scores improved the most did not end up with higher scores on the hypoxia questionnaire (Table 5). This questionnaire was a traditional, content-based assessment of their knowledge of the causes of hypoxia. However, even when students' scores were lower than desired, indicating their incomplete understanding of the causes of hypoxia, a number of them were able to fully describe a number of consequences of hypoxia in their third essay.

TABLE 5. Mean Concept Map Scores

Essay 1 → Essay 3	Concept Map 1	Concept Map 2	Concept Map 3	Hypoxia Questionnaire (%)
No change	0.24	0.37	0.33	68
Increased one category	0.21	0.43	0.40	64
Increased two categories	0.12	0.26	0.32	53

Note. For Concept Maps 1–3, C:I (number of concepts [C] per number of items [I]). Students are grouped by degree of change in their ecological literacy rating from Essay 1 to 3.

TABLE 6. Sample Excerpts From Student Essays

Category	Example statements
Superficial	"Population is a large concept of dead zones."
	"I personally feel that there is going to be something done about hypoxia and that it will get better for all of us."
	"The algae concept is an ecological one."
Subjective	"I know my dad would be much more crabby if he was not able to fish like he can. I also think that our family would miss the fish meals that we are now able to eat, if they were gone."
	"When I first heard about hypoxia it made me mad that we had a hand in this. So many emotions are running through me."
	"This whole situation bothers me but at the same time, I don't really care. . . ; fishing and farming are not big issues to me since I grew up in cities."
Objective	"Because of high number of dead algae providing food for the bacteria, the population size of the bacteria explodes."
	"Because of the limiting resource of oxygen many fish and organism die. All living organisms need oxygen to live but too much or too little will kill them."
Authentic	"I have been married to a 4th generation farmer for the past 25 years. The main source of information for the farmer is the local agronomist who advises them on everything from pest control, to planting rotation, chemical application, to soil erosion, it is their job to boost production, not to control dead zones in the gulf, this is the sad reality. Personally I have struggled with this for years, I have been concerned about what chemicals were doing to our local environment but more importantly, what they are doing to my husband and sons, who are directly exposed to them all summer long. Chemical application and farming go hand in hand, there are few farming operations that are willing to risk their livelihood and their traditional way of life to convert their farm to an organic operation, the risks are just too great. I don't think that there is a simple solution, the best that I can hope for is that as farmers, my family will continue to make progress in their efforts to reduce the amount of chemicals we apply, and to use alternate tillage methods that decrease erosion."
Professional identity	"I feel that by pursuing a career in education I will be in a position where I will be able to directly educate many young people at a young age."
	"I, as a person of the community, could hold a seminar and educate my audience about hypoxia and why it is an important issue."

Note. All quotations above are taken directly from students' writing in Essays 1 to 3.

Discussion and Summary

We found that with guided writing activities based on the CAB-WTL model, most students obtained a higher degree of ecological literacy. Of the 22 students, 14 (64%) improved in their literacy level. However, we recognize that our sample size was not large. We consider our findings promising, and we are encouraged to pursue this project. One limitation we identified was that students were not given an opportunity to transfer their ecological understanding in a nonguided written assignment. Therefore, we are currently testing this activity.

The magnitude of change varied in interesting ways among different types of students. The following students in our study did not increase their ecological literacy score as dramatically as did their peers: (a) the objective learners who remained stuck in the objective category but scored high on traditional assignments and assessments, (b) the superficial learners who had trouble with making even the most basic ecological connections, and (c) the subjective learners who were passionate about issues but could not effectively integrate conceptual knowledge into their arguments.

Students who improved the most in their essays, most notably the ones who went from the superficial to the authentic learners category, did not necessarily show a complete understanding of hypoxia. Nevertheless, these students were the only ones who broadened their conceptual framework of ecology during the course of the guided writing activities, as shown by their continued improvement on their concept maps. It is clear that these students were disproportionately and positively affected by the writing activities. It is important to note that the majority of students showed an improvement in identifying decisions to address ecological dilemmas. The CAB-WTL model reinforced critical thinking skills even in those students who had been classified as authentic writers since the first essay. A few students demonstrated adequate conceptual understanding of hypoxia but did not identify any personal connections, despite clear instructions to do so. These students are typical of those who can excel in traditional science classes though they may fall short of achieving full ecological literacy. The Hypoxia Questionnaire scores were not as high as we had expected. We speculate that students treated the questionnaire as a low-stakes assessment because it was not labeled *quiz* or *test*. In our subsequent study, we use the terms *pretest* and *posttest* and have found that students seem to spend more time responding to the questions.

Activities that are reflective, such as expressive writing, encourage students to be critical of their own understanding (D'Avanzo, 2003). In turn, students who are more metacognitive are most likely to be actively involved in the process of their learning by addressing their confusion (D'Avanzo; Mason 1998,). Bereiter and Scardamalia (1987) pointed out that the reflection phase, during which the writer must modify his or her thoughts to accommodate changes in the composition, is critical for meaningful learning. Because guided writing activities require students to be reflective and self-critical, we feel that instructors, with continued use of the CAB-WTL heuristic, can increase the overall ecological literacy of significant proportions of students. In addition, because many universities require nonscience students to take general education science courses, while encouraging all instructors to integrate more writing into their curricula, the CAB-WTL model can meet the several goals of university educators.

Instructors can use the CAB-WTL model to introduce nonmajors to scientific reasoning skills, integrate writing activities into science classes, and increase ecological literacy of college students. Writing is consistent with constructivist teaching philosophies because it allows students to draw on their own knowledge (Wellington & Osborne, 2001). Likewise, writing allows students to piece together prior knowledge with newly acquired knowledge in a meaningful way. One limitation of the present study was that the CAB-WTL model was tested in one class with one instructor. Hence, we are expanding our study and testing the CAB-WTL model in three scientific disciplines (biology, chemistry, and physics) at the college level. By using this model in different subject areas with multiple instructors (at this point, eight instructors are implementing the model in their classes as part of our project), we can study the transferability of the CAB-WTL. Another limitation of the present study is that students have often been taught to write in a distant, third-person point of view. In our subsequent studies, we plan to include both student interviews and an opportunity for students to write a fourth essay, prompted by a different reading passage, to test their ability to transfer first-person writing skills from one topic that involves guided writing to a completely new topic. By allowing students to express themselves orally and on a new topic, we can better assess the effects of our writing heuristic.

We conclude that ecological literacy occurs on a continuum. Authentic learners who can recognize dilemmas, possible decisions, and their ecological consequences are on one end of this continuum. At the other end are the superficial and subjective learners, who do not demonstrate a conceptual framework that is adequate for explaining how their actions may have ecological impacts. The goal of educators should be to encourage each student to move along the continuum toward ecological literacy, and, as our findings illustrate, guided writing activities have encouraged this movement for the majority of the students in this study. It is likely that this guided writing model could be implemented in other undergraduate courses and scientific disciplines and prove equally effective for helping students to achieve scientific ecological literacy.

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References

Adeniyi, E. O. (1985). Misconceptions of selected ecological concepts held by some Nigerian students. *Journal of Biological Education, 19,* 311–346.

Balgopal, M. M. (2007). Examining undergraduate understanding of natural selection and evolution. (Doctoral dissertation, North Dakota State University, 2007) *Dissertation Abstracts International, 68*(05), 273.

Barrett, G. W. (2001). Closing the ecological cycle: The emergence of the integrative cycle. *Ecosystem Health, 7*(2), 79–84.

Bereiter, C., & Scardamalia, M. (1987). *Psychology of written composition*. Hillsdale, NY: Erlbaum.

Berkowitz, A. R. (2007). *Towards a definition of ecological literacy.* Cary Institute of Ecosystem Studies. Retrieved May 8, 2007, from http://www.ecostudies.org/people_sci_berkowitz_literacy.html

Bowers, C. A. (1996). The cultural dimensions of ecological literacy. *The Journal of Environmental Education, 27*(2), 5–11.

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

Brody, M. (2002). Park visitors' understandings, values and beliefs related to their experience at Midway Geyser Basin, Yellowstone National Park, USA. *International Journal of Science Education, 24,* 1119–1141.

Bybee, R. W. (1993). *Reforming science education: Social perspectives & personal reflections.* New York: Teachers College Press.

Carlson, C. A. (2007). A simple approach to improving student writing. *Journal of College Science Teaching, 36*(6), 48–53.

Case, J. M., & Fraser, D. M. (1999). An investigation into chemical engineering students' understanding of the mole and the use of concrete activities to promote conceptual change. *International Journal of Science Education, 21,* 1237–1249.

Cutter-MacKenzie, A., & Smith, R. (2003). Ecological literacy: The 'missing paradigm' in environmental education (part one). *Environmental Education Research, 9,* 497–524.

D'Avanzo, C. (2003). Application of research on learning to college teaching: Ecological examples. *Bioscience, 53,* 1121–1128.

Davidson, J. (2003). Citizenship and sustainability in dependent island communities: The case of the Huon Valley region in southern Tasmania. *Local Environment, 8,* 527–540.

Ekborg, M. (2005). Student-teachers' learning outcomes during science subject matter courses. *International Journal of Science Education, 27*(14), 1671–1694.

Futuyma, D. (2007). Science's greatest challenge. *Bioscience, 57*(1), 3.

Grace, M. M., & Ratcliffe, M. (2002). The science and values young people draw upon to make decisions about biological conservation issues. *International Journal of Science Education, 24,* 1157–1169.

Hand, B., & Prain, V. (2004). A research program on writing for learning in science, 1992–2002. In C. S. Wallace, B. Hand, & V. Prain (Eds.), *Writing and learning in the science classroom* (pp. 47–66). Dordrecht, The Netherlands: Kluwer Academic.

Hart, P. (2002). Environment in the science curriculum: The politics of change in Pan-Canadian science curriculum developmental process. *International Journal of Science Education, 24,* 1239–1254.

Jimenez-Aleixandre, M.-P. (2002). Knowledge producers or knowledge consumers? Argumentation and decision making about environmental management. *International Journal of Science Education, 24,* 1171–1190.

Jones, M. G., Carter, G., & Rua, M. J. (2000). Exploring the development of conceptual ecologies: Communities of concepts related to convention and heat. *Journal of Research in Science Teaching, 37,* 139–159.

Keys, C. W. (1999). Revitalizing instruction in scientific genres: Connecting knowledge production with writing to learn in science. *Science Education, 83,* 115–130.

Kinchin, I. M., Hay, D. B., & Adams, A. (2000). How a qualitative approach to concept map anlaysis can be used to aid learning by illustrating patterns of conceptual development. *Educational Research, 42*(1), 43–57.

Leach, J., Driver, P., Scott, P., & Wood-Robinson, C. (1996). Children's ideas about Ecology 2: Ideas found in children aged 5-16 about the cycling of matter. *International Journal of Science Education, 18,* 19–34.
Liem, A. (2005). Promoting science literacy by engaging the public. *PLoS Biology, 3,* e427.
Liu, X. (2004). Using concept mapping for assessing and promoting relational conceptual change in science. *Science Education, 88,* 373–396.
Louv, R. (2006). *Last child in the woods: Saving our children from nature-deficit disorder.* Chapel Hill, NC: Algonquin Books.
Mason, L. (1998). Sharing cognition to construct scientific knowledge in school context: The role of oral and written discourse. *Instructional Science, 26,* 359–389.
Mintzes, J. J., Wandersee, H. H., & Novak, J. D. (2000). *Teaching science for understanding: A human constructivist view.* San Diego: Academic Press.
Munson, B. H. (1994). Ecological misconceptions. *The Journal of Environmental Education, 25*(4), 30–34.
National Research Council (NRC). (1996). *National science education standards.* Washington, DC: National Academy Press.
Novak, J. D., & Gowin, B. D. (1984). *Learning how to learn.* Cambridge, England: Cambridge University Press.
Oers, B. V., & Wardekker, W. (1999). On becoming an authentic learner: Semiotic activity in the early grades. *Journal of Curriculum Studies, 31,* 229–249.
Orr, D. W. (1989). Environmental education and ecological literacy. *Holistic Education Review, II,* 48–53.
Orr, D. W. (1992). Ecological literacy: Education and the transition to a postmodern world. Albany: State University of New York Press.
Raloff, J. (2004a, June 5). Dead waters: Massive oxygen-starved zones are developing along the world's coasts. *Science News, 165,* 360–362.
Raloff, J. (2004b, June 12). Limiting dead zones: How to curb river pollution and save the Gulf of Mexico. *Science News, 165,* 378–380.
Rivard, L. P. (2004). Are language based activities in science effective for all students, including low achievers? *Science Education, 88,* 420–442.
Rivard, L. P., & Straw, S. B. (2000). The effect of talk and writing on learning science: An exploratory study. *Science Education, 84,* 566–593.
Roth, C. E. (1992). 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 in theory and practice.* Newark, DE: International Reading Association.
Shanahan, C. (2004). Better textbooks, better readers and writers. In E. W. Saul (Ed.), *Crossing borders in literacy and science instruction* (pp. 370–382). Newark, DE: International Reading Association.
Slavin, R.E. (2003) *Educational psychology: Theory and practice* (7th ed.). Boston: Allyn and Bacon.
Slingsby, D. (2001). Perceptions of ecology: Bridging the gap between academia and public through education and communication. *Bulletin of Ecological Society of America, 82*(2), 142–148.
Sousa, D. A. (2001). *How the brain learns* (2nd ed.). Thousand Oaks, CA: Sage.
Stamp, N. (2005). The problem with the messages of plant-herbivore interactions in ecology textbooks. *Bulletin of the Ecological Society of America, 86*(1), 27–31.
Stone, M. K., & Barlow, Z. (2005). *Ecological literacy: Education our children for a sustainable world.* San Francisco: Sierra Club Books.
Summers, M., Kruger, C., Childs, A., & Mant, J. (2001). Understanding the science of environmental issues: Development of a subject knowledge guide for primary teacher education. *International Journal of Science Education, 23,* 33–53.
Uno, G. E., & Bybee, R. W. (1994). Understanding the dimensions of biological literacy. *Bioscience, 44,* 553–557.
van Weelie, D. (2002). Making biodiversity meaningful through environmental education. *International Journal of Science Education, 24,* 1143–1156.
Wallace, C. S., Hand, B., & Yang, E.-M. (2004). The science writing heuristic: Using writing as a tool for learning in the laboratory. In E. W. Saul (Ed.), *Crossing borders in literacy and science instruction* (pp. 355–368). Arlington, VA: National Science Teachers Association Press.
Wellington, J., & Osborne, J. (2001). *Language and literacy in science education.* Buckingham, England: Open University Press.
Yeung, L., & Law, N. (2001). Explorations in promoting conceptual change in electrical concepts via ontological category shift. *International Journal of Science Education, 23,* 111–149.

APPENDIX

Exploring Biology Writing Assignment I

Directions

1) ***Compose an essay*** during class in which you include the following:
    a. Identify and describe ecological concepts you noticed in the set of articles.
    b. Provide an example for each concept you identified and describe how they illustrate the concepts and help you to better understand them.
2) ***Use your articles*** as references as you compose your essay. You may wish to underline, circle, or otherwise identify key points in the articles if you have not done so already.

3) ***Please type your essay!*** Make sure you have time to type your essay on one of the computers during class. Do not forget to put your name and the date on each page of your essay.
4) ***Hand in*** your typed essay and your article packet before you leave.

Grading
Each essay is worth 20 points. There are four categories that will be considered in evaluating your essay, with each worth 5 points:

1. Did you identify and describe several ecological concepts?
2. How well did you support these concepts with examples?
3. Did you use correct grammar and syntax in your essay?
4. In there evidence that you actively read the articles?

Exploring Biology Writing Assignment II

Directions
1) ***Add the following components*** to your essay during class:
   a. Describe how you feel about the story that is communicated in each of the articles.
   b. Describe how other members of society may feel about the story that is communicated in each of these articles.
2) ***Please type your essay!*** Make sure you have time to type your revised essay on one of the computers during class. Do not forget to put your name and the date on each page of your essay.
3) ***Hand in*** your typed, revised essay before you leave.

Grading
Each essay is worth 20 points. There are four categories that will be considered in evaluating your essay, with each worth 5 points:

1. Did you describe your reaction to each of the two articles?
2. Did you imagine how others may react to each of the two articles?
3. Were your descriptions detailed and specific?
4. Did you use correct grammar and syntax in your essay?

Exploring Biology Writing Assignment III

Directions
1) ***Add the following components*** to your essay during class:
   a. Identify at least one dilemma that a member of society may experience after reading these articles.
   b. Imagine how this person may resolve the dilemma and describe.
   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 you have time to type your revised essay on one of the computers during class. Do not forget to put your name and the date on each page of your essay.
3) ***Hand in*** your typed, revised essay before you leave.

Grading
Each essay is worth 20 points. There are four categories that will be considered in evaluating your essay, with each worth 5 points:

1. Did you identify a dilemma that someone may experience after reading the articles?
2. Did you describe how this person might resolve this dilemma?
3. Did you explain your level of identification with this dilemma and if applicable, mention possible ways you may address the dilemma on a personal basis?
4. Did you use correct grammar and syntax in your essay?

Hypoxia Questionnaire

1. Which abiotic factor dramatically decreases in aquatic ecosystems that are experiencing hypoxia?
2. What effects can this decrease have on animal populations?
3. What do humans do that is the major, although indirect cause of hypoxia?
4. If nutrients are increased, how is it that oxygen conditions get so low? Explain this using algae and bacteria in your answer.
5. List at least two ways hypoxia could be prevented, or least limited.