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Meaning making: What reflective essays reveal about biology students' conceptions about natural selection

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Abstract The process of reflective writing can play a central role in making meaning as learners process new information and connect it to prior knowledge. An examination of the written discourse can therefore be revealing of learners' cognitive understanding and affective (beliefs, feelings, motivation to learn) responses to concepts. Despite reflective writing being an important learning tool, the role of this genre in upper-division college biology courses has not been well studied. This paper examines how nineteen physiological ecology students wrote about their understanding of natural selection and adaptations in ten reflective essays and describes how a model of student meaning making was developed. Qualitative essay analysis (through a triangulation of data: class observations; essays; and transcribed interviews) revealed that students could be classified into four categories of writers: *subjective* (personal, affective connections); *objective* (conceptual, cognitive connections); *authentic* (both affective and cognitive connections); and *superficial* (no supportive connections or claims). In-depth case studies illustrating these four categories are presented. Implications for college science instruction are discussed.

Keywords Writing · Learning · Affective · Cognitive · Authentic · Undergraduate

Introduction

This study explores how learners *make meaning* of the scientific discourse that occurs in their formal learning environments. Learners are influenced by scientific discourse in the form of lectures, classroom discussion, reading, inquiry activities and other classroom exercises. Learners, likewise, may contribute to science class discourse both through writing or speaking opportunities. Through examinations of student written discourse in

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science classrooms we can learn what learners know (Fellows 1994); how they create their own scientific voice (Gee 2002; Wallace 2004); how they reflect on their beliefs (Mason and Buscolo 2000); and how they make meaning of scientific concepts (Balgopal 2007; Balgopal and Wallace 2009). An analysis of science writing, therefore, allows instructors to study how learners make sense of scientific concepts (Osborne and Wittrock 1983; Shahn and Costello 2000).

Because writing is a critical process in the learning of scientific concepts, especially as learners struggle through interpretations of science concepts (Davis 2003; Mason 1998; Saul 2002; Wallace et al. 2004), researchers can use the written products as windows into the learners' minds (Fellows 1994). Sometimes learners' struggles involve both affective and cognitive negotiations as they try to make meaning of new ideas that have been introduced in their learning environments. For example, McLeod (1997) found that written composition revealed more than just cognitive understanding of a concept; it exposed learners' beliefs about a topic. Learners' emotive responses to concepts that did not emerge in oral discourse instead were integrated into written discourse. Students may have felt more comfortable expresses affective responses to concepts in writing then during class discussions.

Writing in science classes helps learners make sense of concepts (e.g., Saul 2002; Wallace 2004; Wallace et al. 2004); however, learners may be unable to express their scientific conceptions using acceptable scientific language (Balgopal 2007). Gee (2002) purported that in order for learners to make meaning of scientific discourse, they must be willing to use academic language, accept that at times they must replace their personal language with academic language, communicate with other "experts" in scientific discourse, and be engaged in Discourse spaces beyond simple conversational contexts (Gee 2002). Gee uses Discourse with a capital D to signify that discourse within social experiences is socially and culturally bound. Hence, everyday language is sometimes at odds with academic scientific language because they are constructed within different contexts and can carry different meanings. As learners make meaning of scientific concepts, they must negotiate their own use of language that expresses their conceptions while remaining scientifically acceptable. Moreover, examining learners' written products may help instructors understand how students make meaning of concepts and figure out what language to use.

Wallace (2004) asserted that the "authentic use of language" requires a learner to be able to incorporate academic scientific discourse into his/her everyday language. She presented a theoretical framework to study scientific discourse using three analytic lenses: authenticity, multiple discourses, and "Bhabha's Third Space" (2004). These three dimensions all examine how learners move from private to public discourse spaces in terms of how (a) they *express* themselves, (b) the *voice* (self-talk or authoritative) they use, and (c) their willingness to move into a Third Space to find *common meaning* between writer/speaker and reader/listener. According to Levin and Wagner (2006) writers may view their discourse as being either closed or open, creative spaces, which may affect how common meaning is found. In their study of informal science writing and metaphors, Levin and Wagner (2006) identified four different dimensions of written discourse: *cognitive*, *affective*, *social*, *and meta-cognitive*. If writing was perceived as a closed process, then writers were less risk taking and were not sensitive to the social contexts. Returning to Wallace's framework, we might explain that learners who have this "closed" (along a right/wrong continuum) perception may be less willing to move into a Third Space, where they can negotiate a common language between "self" and "other." In addition, writers must be able to recognize that there are many forms of discourse and that each can be socially constructed (Wallace 2004), if they are to be classified as being metacognitive.

Drawing from both Wallace (2004) and Levin and Wagner's (2006) studies, we examined reflective essays written by undergraduate biology students in an upper division ecology course. We were intrigued with how learners defended their claims—how they integrated evidence from both their personal and academic "funds of knowledge" (Moll et al. 1992). We were interested in how learners expressed themselves and how they *made meaning* of scientific concepts discussed during their ecology course. A learner who exhibits all four dimensions identified by Levin and Wagner (2006)—affective, cognitive, social, and metacognitive—is classified as being *authentic*, as per Wallace's (2004) definition. We were interested in how authentic learners made meaning of science concepts and whether student written products revealed the meaning making process.

In our study we did not test writing as an instructional intervention. Instead, we examined how learners *made meaning* about (or interpreted) evolution and natural selection through the use of supportive evidence or connections in their reflective writing. We describe how our findings allowed us to construct a 'meaning making' model. Levin and Wagner (2006) encouraged instructors to become aware of their students' views as they make instructional decisions because instruction that is congruent with student learning processes is more meaningful for learners. Similarly, we posit that studying written discourse allows instructors to better understand how their students make meaning of scientific concepts that are discussed in the learning environment. The model that we describe can inform instructors on how to make their instruction more meaningful to learners. Specifically, we believe that the findings of this study will be of interest to instructors by enabling them to develop writing assignments and assessment tools that recognize how learners make sense of abstract scientific concepts.

Theoretical framework

Social-construction of language

We based our study on the premise that knowledge is socially constructed and that language reflects this knowledge (Feldman 2004; Lave and Wenger 1991; Vygotsky 1986). Social interactions involve dialogical communication during which both the messenger and receiver are engaged in discourse. Written discourse, specifically, is generative; the process allows people to piece together prior knowledge with new knowledge (Bereiter and Scardamalia 1987; Britton 1970; Emig 1977; Gee 2002; Keys 1999). Thus, writing can play a central role in the social construction of meaning because writers must consider their discourse community, develop their ideas within social contexts, and describe their mental and emotional states (Levin and Wagner 2006; McLeod 1997; Myers 1990). Knain (2005), in his case study of students and their science journals, found that being able to reflect on written discourse was a generative process that was important for one student, Sophie, who initially felt distressed as she was trying to negotiate how to use "grown up words" (Knain 2005, p. 615). Sophie had not yet adopted the academic science language and felt alienated by it. Through her reflective writing and interview comments, Knain (2005) was able to examine Sophie's search for her science voice. As Sophie's case illustrates, writing can be an emotive process. In addition, learners' perception of the writing process itself can influence their discourse. For example, Levin and Wagner (2006) described how some writers in their study used metaphors that implied that writing required courage because it was a difficult journey. Interestingly, writers in Levin and Wagner's (2006) study used metaphors that already held meaning for them as they described something new. Social

constructivists argue that this is how learners make meaning: by anchoring new knowledge in prior knowledge, constructing conceptions over time.

Within learning environments, learners draw upon prior knowledge as they interpret new information, see their ideas develop on paper, and then commit to these ideas (Bransford et al. 2000; Emig 1977; Levin and Wagner 2006). By drawing on these "funds of knowledge" writers support their claims (Moll et al. 1992). Funds of knowledge may be collected in personal, academic, or professional arenas (Moje et al. 2001). Because writers draw from personal banks of experience (personal and/or academic) their writing is more than just reporting knowledge; it involves constructing knowledge (Halliday and Martin 1993). In some cases, learners may do both—support newly learned concepts with both scientific evidence acquired in a learning environment and those that learners bring with the to their courses.

Science writing genres

In the science classroom, the opportunities for students to write are most often in the form of laboratory reports. Wallace et al. (2004) suggested that the traditional laboratory report genre, prevalent in many biology courses, might not be the most useful form for learners to construct knowledge. Expressive writing, on the other hand, gives learners the freedom to choose how/what evidence will be used to justify their understanding of concepts (Britton 1970; Shahn and Costello 2000). Through this format readers are given insight into the personality and beliefs of the writer. Expressive writing resembles how we communicate in everyday language and serves to convey information and critical feedback (Keys 1999). The term *reflective writing* is a form of expressive writing for which learners are often asked to reflect on a particular prompt (which may either be well or loosely defined) or a directed question (Levin and Wagner 2006; Scott 2005). The reflective process requires that learners think back to what they know and how they support this knowledge (D'Avanzo 2003). Reflective writing is not like knowledge telling (Bereiter and Scardamalia 1987) or science reporting (Wellington and Osborne 2001; Knain 2005) because it requires the writer to analyze his/her personal position and critique his/her conceptual understanding (Levin and Wagner 2006; Scott 2005). Reflection is an important process because it is during this time that new ideas are accommodated by the learner, and is, therefore, a critical and essential part of expressive writing (Bereiter and Scardamalia 1987).

Written reflections are often solicited by prompts, of which there are numerous forms (Davis 2000). Prompts are sometimes very directed without much room for rhetorical freedom. Others are more unstructured and encourage learners to take creative tangents. Davis (2000, 2003) divided prompts into two broad groups: generic (open, "stop and think" type) and directed (requiring writers to monitor their activities). Davis (2003) found that generic prompts enabled middle school science students to develop a better understanding of scientific concepts than their counterparts who responded to directed prompts. In another study Davis (2000) reported that generic prompts yielded more evidence-based claims from writers. She asserted that novices in the science classroom need to see what they know, and reflective writing, in response to generic prompts, provided that opportunity. Warwick et al. (2003) examined a variation of the directed prompt in the form of writing frames. This genre was intended to support laboratory activities in Y4–Y7 classrooms. Warwick et al. (2003) reported that students found writing frames (a series of directed questions that prompt students at different stages of the inquiry) useful when the teacher embodied a constructivist teaching philosophy. Writing in response to text passages or inquiry activities is also used to prompt reflective writing (Reardon 2004). In this case,

reading comprehension is an important component of the learning process (Baker 2004). Ruth and Murphy (1984) rightfully pointed out that a learner must understand a prompt before writing can begin. Hence, "the act of writing actually begins with an act of reading comprehension" (Ruth and Murphy 1984, p. 410).

Analyzing writing process

Whether learners are constructing new knowledge or not, their writing can indicate how they make meaning of what they already know or what new knowledge they have gained. In order to understand the role that writing plays in knowledge generation writing researchers have developed two theoretical models; however, neither of these models explains how written discourse reveals how learners make meaning of science concepts. Flower and Hayes (1980) described their Cognitive Process Theory of Writing (CPTW) as a series of tasks. The first task involves the task environment, in which the writer must consider the purpose and style of the composition. The writer's long-term memory (knowledge of the topic, audience, and writing plans) and the task environment both influence the second task, the actual writing, which may be a lengthy process composed of planning, translating, and revising. Each of these stages can be subdivided into further subtasks, and the entire process may go back and forth. Flower and Hayes explained that the writing process is not linear, nor unidirectional.

A second writing model called the Knowledge Transformational Model (KTM), developed by Bereiter and Scardamalia (1987), describes the process of thinking and writing but with more emphasis on content knowledge. Some writers, they explained, are "immature" and are only able to report what knowledge they have from personal experience, whereas others are more intentional and can set goals and evaluate whether evidence supports their claims. Knowledge telling reflects lower-order (knowledge, comprehension) thinking skills; whereas, knowledge-transformation requires an iterative process dependent on higher-order thinking skills (application, synthesis and evaluation). The KTM does not describe the products of written discourse, rather only the process of creating it. It is likely that the genre of the written product influences the actual process of creating it.

These two aforementioned models describe the processes that writers undertake as they generate new knowledge. However, they do not address the process that writers undergo when they *make meaning* or make sense of scientific conceptions. Neither of the writing models explicitly defines how writers defend their conceptions with examples from personal banks of knowledge. Although, the KTM implies that writers must be able to do so when they synthesize and evaluate their knowledge, this model was not developed to describe how learners make meaning of concepts.

Analyzing written discourse

Analyzing reflective writing, in particular, provides insight into what the writer knows about a scientific concept and how he/she describes his/her conceptual understanding. Levin and Wagner (2006) concluded that as students engaged in reflective writing exercises they were more aware of their own knowledge and were empowered by having the opportunity to express their personal views. Hence, the genre of reflective writing can be very powerful for the researcher who attempts to understand how learners make meaning of abstract scientific concepts. Levin and Wagner (2006) studied how students used metaphors in their reflective writing assignments and found that there were four dimensions of

written discourse: cognitive (knowledge), affective (emotions), social (context), and metacognitive (self awareness). Using these four dimensions they studied how junior high school students wrote using metaphors in informal writing tasks in their science class. They argued that, "by observing [students'] voices as learners we can discover how they make sense of and interpret their learning experiences" (p. 268). Reflective writing affords the learner the chance to analyze his/her emotions and experience, and subsequently synthesize meaning (Levin and Wagner 2006). Written discourse that is supportive of self-questioning and moves away from reporting facts to providing explanations and justifications is what Alvermann (2004) described as a social constructionist process.

We suggest that reflective writing might be considered dialogical in the broad sense that the writer engages in an internal back and forth "conversation" as he/she makes connections between what he/she already knows, is learning, and believes. This, of course, is distinct from social dialogue, but the internal "dialogue" is important in the meaning making process, as Flower and Hayes (1980) and Bereiter and Scardamalia (1987) explained that the writing process allows. In fact, providing justifications and supportive evidence is important in most science writing (Wallace 2004). Teaching learners how to make connections between claims and evidence was the premise for Wallace and Hand (2004) to develop the Science Writing Heuristic (SWH). The SWH helps learners connect expressive personal writing, which has been shown to promote conceptual understanding (Rivard 2004), and traditional laboratory reports, the preferred method of writing in science classrooms. For example, in a study of seventh grade science learners who created their own textbook review questions following the SWH, Wallace and Hand (2004) found that learners who gained ownership of ideas were more reflective as a result. When compared to a control group, learners using the SWH were more engaged, learned how to construct a knowledge claim, and were able to identify gaps in their own understanding of concepts (Wallace and Hand 2004).

Wallace (2004) explained that, "the authentic use of language will involve the appropriation of academic scientific discourse into everyday language." In other words, the *authentic* learner can draw from both cognitive (what they know and understand from academic experiences) and affective (what they believe or feel from personal experiences) funds of knowledge to support written claims. Likewise, Munson and Balgopal (1978) assessed the discourse of their counseling students as being *authentic* if the students could find the "right" mix of professional and personal proximity to their group members. Students who chose to only make cognitive connections and maintained an affective distance from the concepts were labeled *objective*, whereas, those whose discourse only made personal connections without substantive support were labeled *subjective* (Munson and Balgopal 1978).

Making meaning of evolution and natural selection

In this study, we focused on how learners negotiated the meaning of evolution and natural selection. Evolutionary theory has been well documented to be particularly confusing and abstract for college learners, even though it is considered a unifying theme in the natural sciences (Anderson et al. 2002; Southerland et al. 2001; Lawson et al. 2000). Learners enter classrooms with preconceptions based on religious teachings or poorly formed ideas from incomplete high school instruction on evolution. Many learners define natural selection as "survival of the fittest" without understanding this circular phrase (Bishop and Anderson 1990). *Fitness* can be defined as the reproductive potential of an organism and is traditionally measured by survival and fecundity. An organism that survives, therefore, is

already demonstrating some level of fitness. Futuyma (1986) provides a more complete definition of natural selection: "it is no more than a statistical measure of the difference in survival and reproduction among entities that differ in one or more characteristics…natural selection operates whenever genotypes differ in fitness (pp. 150–151)." Even if learners are able to understand this definition, they are not always able to transfer their knowledge to specific contexts and support their understanding with examples. There has been a plethora of research on natural selection understanding, misconceptions, and conceptual change, but very few of these are within the context of undergraduate biology majors' classrooms (see Ingram and Nelson 2006). The focus of our study, therefore, was to analyze student written discourse regarding evolution and natural selection in an undergraduate, upper-class ecology course. The guiding research questions were:

1. What types of evidence do learners use to support their claims about evolution and natural selection in their reflective writing?
2. As students draw from different funds of knowledge what does their writing reveal about how they make meaning of evolution and natural selection?

Methods

Participants and research context

Using the grounded theory approach for analysis was logical in this study because it was naturalistic, and we began the study with no pre-conceived ideas of how participants would make meaning of natural selection in their written discourse. Balgopal was embedded in the environment as a participant observer for every class throughout the fifteen-week physiological ecology course. The course was geared towards upper-division biology and zoology majors at an upper mid-western American university, and it focused on behavioral and physiological adaptations of animals. The instructor explicitly stated at the beginning of the semester that the course was rooted in evolutionary principles.

There were 75 students enrolled in the course who were all invited to participate in a larger study on conceptual change of evolution. Nineteen students volunteered to be interviewed three times, although all enrolled students submitted essays as part of their course requirements. Of the volunteers, the average age was 21.5 years, 14 were Euro-American males, 1 was an Afro-Caribbean male, and 4 were Euro-American females. All 19 volunteers were Zoology majors in either their junior or senior years of their undergraduate studies.

Data collected

Several types of data were collected during this study and were triangulated during analyses (Denzin 1989). Data collected included: test scores, transcribed interviews with students and instructor, reflective essays, and participant-observer field notes during each lecture period over the 15-week semester. The instructor administered pre and posttests (*Conceptual Inventory of Natural Selection*-CINS published by Anderson et al. 2002) were administered during class. All students enrolled in the course were asked to electronically submit 10 reflective essays (up to 1.5 pages) during the semester in response either to a directed prompt (sent in by the researcher) or in response to each chapter in *Body Heat* (Blumberg 2002), a non-fiction book that describes behavioral and physiological

adaptations of animals/humans to thermoregulatory pressures. The book is not intended to be a classroom textbook and was written for both scientists and non-scientists.

Volunteers were interviewed three times during the 15-week semester: the first week of class, mid-semester, and during finals week. All interviews were semi-structured, following a set of pre-developed interview questions (see Appendix) with allowances for students to discuss some topics further if they wanted. The first and third interviews centered on a pre and post multiple-choice test (*The Conceptual Inventory of Natural Selection*), and questions were guided by student answers. The complete test questions and pre and posttest data are not presented because this analysis only focuses on interview comments that corroborate written statements. However, we note that this instrument was used and helped frame the semi-structured interviews (1st and 3rd). The second interview involved three questions about variation and natural selection for which students were asked to transfer their understanding from lecture to analyze. Balgopal conducted all interviews and transcriptions (see Appendix for interview questions).

Essay prompts

The instructor gave the students a choice to write reflective essays in response to a non-directed, generic (text) prompt or a directed (question) prompt. As this study was naturalistic, we did not guide the instructor in her teaching or assessment strategies. Of the 19 study participants, 13 chose to respond to direct prompts and six chose to respond to the book chapters. The instructor asked the directed-prompt students to submit 1–2 page essays to her. The directed writers were told that prompts were written in conjunction by the researchers and the instructor but should be e-mailed to the primary researcher. These instructions were intended for organizational purposes and were not meant to imply who the "audience" of the essay was. The instructor made it clear that she would read all essays, as would the researchers. She did not provide the students any specific instruction on writing other than that this was a chance for them to review their ideas about class material.

The instructor graded all essays as done/not done and assigned participation points accordingly. The instructor did not provide individualized feedback to learners but lead discussions about the directed prompts during lecture. The written discourse represents how learners made sense of the conceptual material presented in their learning environment and not necessarily a "conversation" that they had with their instructor. The instructor read the essays as formative assessment and reviewed certain concepts the following class period, if she felt that learners did not demonstrate understanding. Once learners made their initial choice about type of essay prompt, they could not change. The directed prompts were usually in the form of a scenario, and learners were asked to apply the concepts learned in class to answer specific questions. For some essay prompts learners were asked to define terms and describe if they were satisfied or not with their understanding (see Appendix for list of all directed prompts). A total of 285 pages of written discourse were analyzed for this study.

Analysis

Using a constant comparative method (Strauss and Corbin 1990) we coded the written and oral transcripts. It was determined early on, through interviews with participants, that the act of writing was influencing learners' shifting understanding of course material. Questions regarding the role of interviewing, essay writing, perception of researcher and

instructor and studying style were included on subsequent interviews. All interviews were audio taped and transcribed. A total of 4, 275 min of interviews were transcribed and coded. Each essay was read multiple times over a one-year period, and emergent themes were established. With each subsequent reading, codes were further elaborated and connected with one another.

The open coding scheme involved finding salient categories that initially emerged and included those described in Table 1. Charmaz (2005) encouraged grounded theorists to not be overly reliant on "overt" statements and to "create new connections in our theories" by examining "what people say and compare it to what they do" (p. 513). In this vein, we compared what participants said (in their interviews) with what they did (in their writing) to help us identify subsequent codes. Some categories were found to be interconnected and were collapsed to form the axial codes. Finally, the selective codes that were used to develop our proposition included: *subjective* (affectively close, cognitively distant); *objective* (affectively distant, cognitively close); *authentic* (affectively and cognitively close); and *superficial* (affectively and cognitively distant). Some learners did not consistently defend their claims with evidence. We classified some of these individuals as *superficial*. These four emergent categories are described in further detail in the findings section along with a descriptive model.

Establishing trustworthiness

Through prolonged and persistent engagement, triangulation of data, and peer debriefing we tried to establish trustworthiness using Lincoln and Guba's (1985) criteria. Emergent

Table 1 Coding categories used to construct the coding paradigm for this study

Open codes	Axial codes	Selective codes
Conceptual understanding	Personal role in writing	*Superficial writing*
Strong	First person expression	Affectively and cognitively distant
Average	Third person expression	
Weak	Style of writing	*Subjective writing*
Examples used to support concepts	Reflective	Affectively close, cognitively distant
Personal experience	Reporting	
Personal ideas	Emotive comments	*Objective writing*
From lecture	Shared emotional response	Affectively distant, cognitively close
From reading material	Did not share emotional response	
Instances of conceptual change		*Authentic writing*
Positive change	Supporting examples	Affectively and cognitively close
Negative change	From academic experience	
Confusion	From personal experience	
Dissatisfaction		
Response to the instructor or class materials		
Positive		
Negative		
Indifferent		
Type of writing prompt chosen		
Directed		
Non-directed		
Comments about motivation to learn		
Positive		
Neutral		
Negative		

themes were were discussed with our debriefing team, which included five individuals: the two co-authors, the instructor, and two other professors (a rhetoric expert in the English department and a group dynamics theorist in the School of Social Work). Individual perspectives of each validation team member were integrated into the analysis and interpretation of findings, resulting in multiple rounds of coding. Through peer debriefing and discussions (Creswell 1998) emergent themes were established and are presented. The authors' initial interrater agreement was in between 85 and 90%. The instructor then reviewed whether the evidence learners used to support scientific claims was scientifically acceptable. She did this only after the course had been completed. The instructor and researchers read the essays together at the end of the semester and came to consensus on whether or not each writer had a command of the major concepts of evolutionary adaptations. When there was disagreement, we used transcripts, course grade, and essays to come to a joint agreement on coding.

Findings

We classified learners as they made meaning through reflective writing activities using four categories (*superficial, subjective, objective*, and *authentic*), which are presented in a model (Table 2). The Cognitive Affective Affiliation Model (CAAM) was constructed as a result of the analyses in this study to classify how college science students make meaning of natural selection and evolution concepts by making cognitive or affective connections. Affiliation levels are labeled simply as "close" or "distant," yet we recognize that there is a continuum between closeness and distance, so we read Table 2 like a graph. The x-axis represents cognitive levels of affiliation and the y-axis represents affective levels of affiliation. The top right corner is where the authentic, scientifically literate students fall. A *superficial* learner does not provide concrete connections to either conceptual or affective funds of knowledge (Table 3). Moreover, the *superficial* essay appears to be disconnected. The *subjective* learner appears to be focused on making meaning by finding connections to predominantly personal or emotional responses to scientific concepts, and there is little indication of the learner's cognitive understanding of the concept. The *objective* writer, on the other hand, mostly describes their cognitive understanding of the concept, without making any (or few) personal or emotional connections. Finally, the *authentic* writer is able to describe his/her cognitive understanding of the scientific concept, while also describing his/her personal connections or affective responses. These

Table 2 Cognitive and affective affiliation model (CAAM)

Student affiliation with subject matter	**Cognitively distant**	**Cognitively close**
Affectively close		
Affectively distant		

Students who are affectively close find personal connections with scientific concepts; those who are cognitively close find connections that support the concepts being presented in class. Students who are distant do not find connections with the concepts at all. Superficial students can find neither affective nor cognitive connections. Authentic students demonstrate scientific literacy. (recreated from Balgopal 2007)

Table 3 Characteristics of written discourse collected in an undergraduate biology course

Category	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/prior experience
Authentic	Demonstrates and integrates conceptual understanding and personal connections and *behaviors* relating to the issue

four categories are consistent with the dimensions identified by Levin and Wagner (2006) and by Wallace (2004) in their respective studies.

We noted that some students were personally distant on their essays yet were more willing to reveal their affective reaction to concepts or learning environment during interviews. This may relate to their comfort level with an interviewer, their intention of wanting to be personally distant in an essay that may be read by the instructor, and/or because they are exposed to scientific lectures and text that are personally distant (Lemke et al. 2006; Witz et al. 2001).

Findings are presented through five case studies of learners who represent each of the categories (two students are used to describe the authentic category). Of the 190 reflective essays analyzed (10 from each of the 19 participants) it was found that student writing differed in terms of many factors, including voice (first or third person), types of connections made (personal or academic experiences), whether claims were supported with evidence and whether or not the writer reacted emotionally to prompts (Table 3). An important finding was that sometimes learners would support their claim yet, did not elaborate. Although the learner demonstrated that he/she knew that supportive evidence was important, he/she did not expand on how the evidence was relevant. These learners were classified as *superficial* and fell somewhere on the continuum we described in Table 2. For example, Kay stated in one essay,

> In class we talked about how there are certain islands where larger reptiles and smaller mammals are present. This is an example of how evolutionary changes are due to the environment and phenotype. And these changes are seen in a population. Although changes are individual to each animal, there are frequencies that can been [sic] seen in populations of animals

Kay rightfully stated that both environments play a role in how phenotype of different types of animals may evolve. She was responding to a class lecture on allometry, but she did not adequately define how body size is constrained by physiological and environmental conditions. Then, Kay wrote that evolutionary changes are observed at a population level, which is scientifically acceptable. In fact, many students believe that individual organisms evolve. However, Kay did not elaborate on her claims and explain what she meant by frequencies. She was scored as "shallow/close objective" because she rarely used any of her evidence to support claims. She was able to draw on lecture material to partially support her claims; however, she did not convince us that she has moved along the expression continuum (Wallace 2004) to express herself in a "scientific" manner. She was closer to the "vernacular" end of Wallace's continuum.

Eight of the nineteen students used primarily first person voice in their writing, and 11 used primarily a third person voice. Within each of these two groups, writers could be further divided into those who wrote extensively on each concept presented in the prompt, those who explained the concepts but did not further elaborate with other connections than those presented in lecture or in the book, and those who wrote very little substantively about the concept.

A question that emerged during our analysis was whether the type of prompt influenced the types of connections learners made in their essays. This was not the guiding question and because this study was naturalistic, we did not design the instructor assessments to specifically test this question. Nonetheless, it is interesting to note that we did not see a pattern of different types of connections made in our small sample of six non-directed writers and the thirteen directed writers (Table 4). We did find that some of the *authentic* writers responded to the directed prompt, while others wrote in response to the non-directed (text) prompt. All of the *authentic* writers used first voice, especially when making reflective comments about their understanding or connections with personal evidence to support their claim. The one *superficial* writer and one of two *subjective* writers also used

Table 4 Characteristics of all nineteen students who participated in a study on reflective writing and types of connections made to support claims

Student[a]	Prompt	"Academic" connections	Personal connections	Voice	Overall proximity
Stuart	Non-directed	Close	Close	First	Authentic
Jack	Non-directed	Close	Close	First	Authentic
Betsy	Non-directed	Close	Close	First	Authentic
Donovan	Directed	Close	Close	First	Authentic
Chris	Directed	Close	Close	First	Authentic
Christy	Directed	Close	Close	First	Authentic
John	Directed	Close/confused	Close	First	Authentic
Carl	Directed	Close/confused	Close	First	Authentic
Bob	Directed	Close	Distant	Third	Objective
Steve	Directed	Close	Distant	Third	Objective
Dale	Directed	Shallow	Distant	Third	Objective
Tim	Directed	Shallow	Distant	Third	Objective
Dan	Directed	Shallow	Distant	Third	Objective
Kay	Directed	Shallow	Distant	Third	Objective
James	Directed	Shallow	Distant	Third	Objective
Tom	Directed	Shallow	Distant	Third	Objective
Ellen	Non-directed	Shallow	Close	First	Subjective
Mike	Non-directed	Close	Distant	Third	Subjective
Zachary	Non-directed	Distant	Close/shallow	First	Superficial

Non-directed prompts were in response to reading chapters from Body Heat (Blumberg 2002). Directed prompts were guiding questions developed in response to lecture material. Academic connections refer to supporting evidence drawn from coursework, where as personal connections refers to supporting evidence drawn from the learner's own experience. Students who used first person voice usually wrote used "I" statements, and those who used third person voice made more declarative statements. The designations of authentic, subjective, objective, and superficial are based on the definitions provided in Table 2

[a] All names are pseudonyms

first person voice throughout their discourse. All of the *objective* writers, regardless of whether they responded to direct or non-direct prompts, used a third person, passive knowledge-telling voice.

Student discourse was categorized by the proximity of the cognitive or affective statements. Students, who were cognitively close discussed concepts correctly (scientifically), found connections (from lecture, readings, other courses or from personal experience) that supported claims that they made about concepts, and expanded on concepts (evaluated and synthesized ideas). This classification is consistent with Nagasawa et al. (2005) in their study on analyzing written discourse. They found that some students were able to make declarative statements and describe concepts but were unable to support claims with evidence. In our classification scheme these learners were labeled shallow, those who begin using a declarative science voice but never follow through with a detailed explanation of evidence. At least one student in this study did not appear to write about examples that supported concepts, nor did he provide personal reactions to the concepts. He appeared detached from the writing expectations and was labeled as *superficial*.

Affectively close essays were those that revealed students' reflections of the concepts or examples being presented in the book, prompt question, or lecture. These students tended to write in first person and took ownership of their ideas. Sometimes they revealed their personal emotions and reactions to the prompts. Those who were affectively distant used third person voice and revealed no emotional reactions in their essays. However, there were students in this category who did disclose affective responses in written discourse but were very personally revealing in their interviews. For example, Tim is aware of his own confusion. He expresses himself using a private voice and a vernacular expression. He has not mastered the concepts enough to move into a Third Space of negotiated meaning. Our point in illustrating Tim's narrative is not that his content knowledge is lacking but that he uses a more affective tone to his discourse, unlike his written discourse, which involved mostly knowledge telling.

> I don't know. I'd like to maybe go over some hypotheses or just go over how animals change over time. Like, what exactly drives them to do it and if animals themselves are actually changing it or is it all like this works, so this animal is going to produce more offspring. If there is any mental animals saying 'I am going to do this because I am going to make my body do this.'

Of the *authentic*, *objective*, and shallow-*authentic* (those who occasionally were classified as authentic but not consistently) writers all nine were applying to science graduate programs or to professional schools at the time of the study. None of the *subjective* or *superficial* writers expressed plans for further science studies, except for three students who planned on continuing studies in health-related fields. Of the two *subjective* writers one planned on becoming a homemaker and the other had repeatedly withdrawn from his undergraduate studies to fulfill career military obligations. A lack of motivation to move into a Third Space seemed to be influenced by learners' perceptions of the importance of understanding natural selection in their immediate future.

Some students were difficult to classify because either their respective written and oral discourses were not congruent or the instructor and the researchers did not initially agree on the coding of written essays of a student. After discussion of these cases, we came to agreement for classification. All essay excerpts are presented as they were submitted. Interview transcripts are presented with syntax as interpreted from listening to audiotapes. Diction and punctuation have been inserted based on interpretations of utterances. The following case studies were developed to portray the four categories in which students could

be classified in our analysis of knowledge construction. Personal background information, as revealed by the participants, has been presented. The background may not be parallel for each case study because the students chose to share different information with us; however, it provides some degree of background from which each student was writing.

Ellen: A subjective writer

Ellen moved to the midwest from the south and was a senior during the study. Her original intentions were to study Zoology to become a zookeeper, but she confided that she really wanted to stay at home once she gets married and have children. Here Ellen is reacting to a chapter from *Body Heat;* however, she failed to then make any explicit connections to thermoregulatory adaptations.

> It made me think even more about the human race and about temperature. I had never thought about how our temperature is such a big deal to us but when Mr. Blumberg said 'when we are too hot or too cold, we are unable to focus on anything else but our lack of thermal comfort' my first reaction was that it does not matter that much. Then, I remembered last week on those few hot days when I personally got really hot and I had such a hard time concentrating on anything else but ways that I could make myself cooler.

Instead of finding examples in Blumberg's writing that supported evolutionary adaptations–the focus of class discussions, Ellen chose to discuss acclimation. She was not explicit regarding the distinction about "ways that [she] could make [herself] cooler" and thermoregulatory mechanisms that have evolved in humans. Ellen continued to be awed throughout all of her ten essays and is "amazed" by many phenomena described in the chapters. Here she described termites, "I find it so intriguing that animals we might not consider "smart" come up with these amazing ways to live be it how they build their home or some other way of staying alive. Animals are amazing!"

Again, Ellen implied that animal survival is due to their choices and behaviors without mentioning evolutionary adaptations. She did not explain that Blumberg organized this chapter around physical principles of heat exchange (conduction, radiation, evaporation and convection) and the constraint of surface area. Blumberg introduces some examples of behavioral, physiological and physical adaptations related to thermoregulation, and then defines acclimation,

> In addition to evolutionary processes that modify anatomy and physiology across generations, animals can exhibit, over days, weeks, or months, anatomical and physiological changes in response to new local environments. This process is referred to as acclimation or acclimatization, depending on the cause of the change in the environmental conditions (p. 39).

Blumberg uses the termite as an example of a behavioral adaptation (not acclimation) to ventilation and temperature constraints,

> At least one species of African termites has evolved a clever nest design that resolves the conflict between thermal stability and ventilation. The nest consists of a basement, a brood chamber and an attic; the basement is filled with fungus that the termites cultivate so as to produce heat through fermentation. In the attic, channels are dug that pass down the outer wall of the nest and open up in the basement…The warm nest air rises to the attic, where it encounters the cooler air in the wall

> channels. As it loses heat, the air falls down through the channels, and as it falls, the high level of carbon dioxide diffuse through the walls of the nest to the outside air… The air, in other words, is circulated by convection. (p. 43–44).

Although Ellen was amazed by the termite example, she did not write about the evolutionary adaptations that Blumberg was describing. Ellen was almost always positive and optimistic in her responses; however, she changed her tone in Essay 9.

> Then in the last part of the chapter all I could think about was how offended I would be if I were a person who had gone through anorexia and was reading this part. He seems very inconsiderate, and talks about them just as he talks about rats in the other experiments. It is almost as if because people have this problem they would not understand what he is saying and therefore have no feelings on the matter. But then maybe that is what scientists are supposed to do make things less personable and think of it more as just another experiment.

Despite being emotionally revealing, Ellen never described any concepts regarding physiological or behavioral adaptations in any depth. Hence, her essays were coded as cognitively distant. At the same time, she invited the reader into her personal world of interests and reactions; hence, her writing can be described as affectively close. Her interviews generally corroborate the analyses of her essays.

In the following excerpt, Ellen described how she was confused about how scientists decide what to study. As in the previous quotations she spoke about scientists as "others" and did not indicate that she identified with the profession of scientists. Her ideas were difficult to follow since she combined her discussion about "him"—the book author—and "her"—the instructor, perhaps indicating that she was not sure about her claim.

> *Researcher*: So have any of the reflections ever made you think, 'Oh, I am a little bit more confused than I initially thought?'
> *Student*: Not really. Well, a lot of times, when he talks about this and that, I don't see how different people come up with these experiments. Is it just a random thought? "Oh I should do an experiment!" Other than that, not any thing that she's talked about and then he talks about and then I have become confused. Anything that she's gone over and he's built on it. Sometimes he has new ideas; it can be confusing.

Overall, Ellen believed she understood the process of natural selection, yet she struggled with some key concepts. The following excerpt from an interview during which she discussed the origin of variation, on which natural selection works reveals that Ellen was not completely sure about her understanding:

> The reason that variation in body size came about would be because of random changes in gene and different large male and a small female coming together. Like, I know that it happens; that just mutations can cause change like sexual recombination. Last time we got together you asked me when do these mutations occur and I was like, I don't know [laughter]. And that really made me kind of think that I understand overall, but I wouldn't probably be able to tell someone, here's where it happens and this is why.

Christy and Betsy: Two authentic writers

These two writers were the only two of the nineteen who were classified as authentic learners. Not only did these two students discuss the course concepts substantively in their

essays, they were also personally revealing both in their essays and during interviews. These two students truly reflected on the prompts. They described the concepts and then wondered about new ideas that emerged from their own writing. They both supported concepts with personal connections and evidence. Interestingly, these two students were the two of three study subjects who had taken an evolution course prior to this study (the third student, Gary, was a first year Master's student). Only two other students (non study subjects) had had an Evolution class. Christy responded to directed prompts and Betsy responded to the non-directed book prompts.

Betsy was a first year Master's student who had completed her undergraduate degree at a liberal arts college in a neighboring state. She participated in this study during her first semester as a graduate student with an interest in dinosaur adaptive radiation. She was a married, quiet, solitary student who spent her free time with her husband. During interviews she spoke in a clear, confident style and was at ease with herself. The instructor had a positive impression of Betsy and asked her to lead two lectures to the class as part of her course requirements as a graduate student.

Christy was a senior with only seven credits left to graduate with her B.S. in zoology. She had graduated from a local high school as an honors student. She was an independent thinker with strong social and political interests. During the study she was confident in her mannerisms, felt comfortable socializing with other students in the class, especially a group of male athletes from whom she was learning rock climbing. Her goals at the time of the interview were to work for a year to help pay off school loans while applying for graduate programs in ecology and evolution. The instructor spoke positively about Christy and felt that she would succeed in graduate studies.

Betsy was able to synthesize ideas by connecting the concepts presented in *Body Heat* with her prior knowledge. Here she integrated an example about dinosaurs, her research interest, along with her understanding of physiological and morphological constraints and adaptation.

> There are constraints as to how large an organism can grow under it's ideal circumstances. So many adaptations and mutations have occurred over time that a large variance can be seen in plants and animals. An animal can only become so large (or small) before it begins having troubles dissipating or retaining heat, or breathing. The large saurapod "Brontosaurus" or Apatosaurus was once thought to live mostly submerged in watery lagoons or lakes. Modern scientists have since disproved that, citing that with the surrounding water pressure, the animal would not have been capable of breathing. Another example: truly large birds of flight are far and few between. During the last ice age, large vultures called Teratornis with wingspans of up to 7 m were uncovered. Not surprisingly, even with hollow bones, a bird of this size would have needed an enormous updraft to keep itself in the air. This was just getting too big for nature, and be it through natural selection or otherwise, the Teratornis is no longer among us.

In another example, Betsy disclosed personal information as evidence supporting the claims that the author makes and that she found plausible.

> While genes and gametes may determine which sex we are, temperature could determine whether we exist or not. In order to reproduce, an animal actually has to reach reproductive age. If that animal's mother had a high fever at one point, it may end up having faulty reproductive organs, developmental problems or other detrimental effects which may render the animal unable to reproduce… As a personal

> experience, my godparents gave birth to a healthy girl. Shortly after birth, however, she came down with an extremely high fever. This fever left her permanently mentally handicapped. Our bodies are very touchy as to its preferred temperature range, as with other animals. Along with the last chapter, animals will behaviorally attempt to alter their temperatures, be it moving into shade or warming on a rock to keep the status quo.

Christy, like Betsy, had a strong understanding of the concepts presented in class and demonstrated this in both her written and oral discourses.

> Genes + environment = phenotype. I like the example [the instructor] used in class about hair length. Ones genes determine their natural hair color, thickness, etc. The environment one lives in determines hairstyle, length, etc. Thus genes of the individual and the environment that one is determines how one looks, behaves, and even has an effect on one's physiological systems. If an individual is predisposed to high blood-pressure because their parents and grandparents have high blood-pressure the individual may be able to live healthily for years without it being a factor. However, if this individual decides to eat high fat and high cholesterol foods (environmental stimulus) this individual is more likely to see adverse affects than if they ate a healthy diet and exercised regularly. Genes (predisposition) + environment (eating habits) = phenotype (blood pressure).

As Betsy had integrated a personal example (dinosaurs), Christy also supported the concept with her own example (blood pressure). Christy's oral discourse supports her authentic learning style (through close cognitive and affective proximity). In the following excerpt, she describes the same concept of genetic by environmental interactions with another self-generated example.

> I was taking [a Human Development] class. They saw that you have twins that are 98% homologous on every chromosome and you separate them at birth and put them in two different environments. They have similarities and differences and why is this?…. Let's say a wolf has a brother, one leaves and one stays with the pack…. They are both going to grow up very differently even though they have very similar genes.

Both Betsy and Christy were able to describe examples in either lecture or in prompts (book or directed questions) within the context of a larger concept, and then synthesize ideas by weaving in their own evidence to provide further support for a claim. Both of these students explained their understanding in depth and frequently turned in one-page essays as opposed to many students who submitted one-paragraph answers.

Steve: An objective writer

Steve is an example of an objective writer who responded to directed questions. The instructor described him as a bright capable student who earned a very high grade in this course. He was a motivated student and athlete and was preparing for post-graduate studies. Steve grew up in the upper Midwest on a farm. He described himself as a hard-working student who liked to go home, help on the farm and hang out with friends. He had a good rapport with the instructor and researcher and was always pleasant and polite. By the end of the semester he found out that he had earned admission to veterinary school in a western state and planned to become a large animal veterinarian.

Steve used both first and third person voices depending on the directed prompt. If the prompt asked "what do you think" or "what would you expect," he answered in first person as illustrated in the following excerpt from an essay.

R: In an environment with just snail kites what type of snails would you expect to see and why?
S: Initially I would expect to see many lighter colored snails because why would the snail kites be there if they didn't have access to their snail of choice. But after a while I would expect snails that were darker in color. Since the snail kites prefer lighter-colored snails, those having a darker color would have a better chance to survive and reproduce, sending their genes diving into the gene pool of future generations.

Steve begins his answer in first person but quickly switches to a third person voice and explains his answer in an objective manner. He demonstrates understanding of the importance of variation and differential survival and reproduction as they relate to natural selection. Although he was listed as using both voices, the majority of Steve's essay answers were written in third person voice.

The snail kite example ended up being an important example for Steve. When asked to think of examples (either from lecture or personal knowledge) to support a concept related to adaptation, he often chose the snail kite example. He discussed it twice more in essays and twice during interviews, including in December although the snail kite/limpkin scenario was first introduced by the instructor the first week of October. Steve, therefore, was able to demonstrate his understanding using examples, yet he did not generate any obviously personal (from outside of class) examples.

In response to a question asking students to reflect on physiological adaptations that the instructor had been discussing in class, Steve wrote

Another adaptation is common to almost all aquatic species: gills! Gills are extremely efficient means of extracting oxygen from the water, as between 80 and 90% of oxygen is obtained. There are different ways that organisms use their gills to extract the oxygen–buccal pumping and RAM ventilation. Buccal pumping is an actual pumping process that uses differences in pressure to move the water, and RAM ventilation relies on locomotion to keep the water flowing over the gills.

Although Steve's response appears to be listing scientific facts, he also is synthesizing information by evaluating the efficiency of two types of respiratory strategies and comparing how they work. This passage is typical of his objective writing style using information initially presented in lecture.

During his interview Steve explained that he believes concepts when he has examples to support it. "When there were examples it convinced me." Later on when asked,

R: "When you can't find examples, how do you resolve that conflict?"
S: "I don't know. Then I just have to, as you said, take it at face value and just accept it. Hopefully, I can understand it without examples. If I don't get examples, it's kind of hard."
R: Do you look for examples yourself or do you wait till the instructor gives them to you?
S: I look for them usually all the time and when they [instructors] give them, it's nice. I try to think of examples for like $P = G + E$. I don't know. I look everywhere. I don't really look in books. A lot of times I ask friends when I study with them. I get a lot more out of explaining things to them.

In fact, when examining Steve's essays and transcripts of his interviews, he only provided examples that were from the course. When asked questions that were intended to personalize examples, his response was to smile and laugh. For examples, when asking Steve why organisms are different during a conversation about variation, we asked him to explain why he and his brother [he had said in an earlier casual conversation that he had a brother and a sister] looked different. He laughed and was silent. When we followed up by asking why two deer siblings were different, he began to explain what he understood about genetic and environmental aspects of phenotype. In another example when discussing phenotype, Steve used the example used by the instructor in the course

> Phenotype of an organism–what you can measure, it's physiology, how it looks, is affected by genes and environment. An example would be hair color. Like, it could be, like, your genotype would say black or brown hair or whatever, but then you can go and dye it and that would be an environmental factor."

The interviewer said to Steve, "so, if you saw my hair, you'd document and measure it as 'black,' but you don't know if I was born with black hair or if I went and dyed it?" Steve laughed and nodded "yes." Perhaps he was uncomfortable with the personalization of examples, although he did not appear to be. Rather, it appeared that he preferred to discuss all examples in an objective and non-personal manner.

That Steve did not generate any new examples in his ten essays and three interviews is the reason why he was classified as a cognitively close yet affectively distant writer. He preferred responding to questions rather than reflecting without direction, as he explained during his second interview. "I would rather answer a direct question or else I wouldn't feel I would be answering the assignment." For Steve, this learning style had enabled him to succeed, so he was pleased with his learning behavior.

> I don't think I will change [my studying habits] because I know what I need to do to study to learn things. I will keep doing what I do. I love having examples. Give me a thousand examples of something and I learn it very easily.

In short, Steve had a solid understanding of the concepts and had learned how to succeed in his college science courses—which do not always evaluate self-reflective skills.

Zachary: A superficial writer

Zachary is an interesting case because he was only partially involved in assignments and the course. He was a very marginal student with sporadic attendance, and when asked for impressions, the instructor could not remember what he looked like. He never asked questions of the instructor during or outside of lecture. He roomed with another student, who had also volunteered to be a part of this study. He only submitted four of his ten essays and sat for only two of the three interview sessions. He has been included as a case study because his essays could not be coded as either cognitively or affectively close. He is an example of a superficial student. If he had participated more fully, he likely would have been classified as subjective.

Here Zachary, although interested in the topic of thermoregulation, cannot demonstrate an understanding of behavioral or physiological adaptations. Zachary's understanding of evolutionary adaptations was that the environment "does things for us." His worldview was very anthropocentric and teleological.

> I found Body Heat to be really interesting with the facts that it has in it. About how they use temperature to find the Earth's age and the time of death of a body [sic]. It gave me a lot of information I didn't know or just never really thought of it. The way the environment basically does all these sort of things for us and or how we came to be to live in the environment like the otter with the antifreeze in its blood to help it survive the cold.

During interviews, as well, Zachary was unable to demonstrate an understanding of evolutionary adaptations as a unifying theme.

> *R*: Could you describe the connection between [the instructor's] course and the book?
> *S*: well, like she was talking about thermoregulation and stuff and the book was talking about thermoregulation and pregnancy and if it goes up so much degrees in the stomach, the baby has trouble like surviving and has bad stuff happened and stuff like that.
> *R*: Have you read any other books similar to this?
> *S*: No, I like non-fiction stuff on serial killers and Da Vinci Code type of books. If I had known what was in [Body Heat] I would have [read it on my own], but there was no way of knowing any of that.

Zachary could not find the concepts of physiological and behavioral adaptations connecting book with lecture material. He focused on specific examples in the text. Even as he discussed his reading interests, he did not seem to be proactive in learning. He explained to us that he does not read books about science because he would not know what they are about unless he read them first. His solution was to not read them at all. His circular argument was indicative of his apathetic attitude towards learning which is corroborated by his low course grade, his sporadic course attendance, his failure to submit more than four of his assigned ten essays or to show up to his final interview session.

Zachary began to describe personal examples, but did not support his claims. His "connections" were examples of how the book text was fodder for thought, yet Zachary did not finish the reflection by connecting text examples with the scientific concepts discussed in class. This was Zachary's longest reflection.

> As I was reading about the infants being able to basically rebuild themselves because their immune system tends to be better. It reminded me that this must be why parents want to get their kids the chicken pox at an early age instead of later. I also thought that it could be why some doctors disagree with giving children medicine when they know that they will be alright and not become immune to it, because whey [sic] they are older they may get sick and already be immune to the medicine given.

Zachary seemed to have completely missed the author's point in this chapter. In this chapter, the author was, in fact, explaining how fevers evolved in animals as diverse as reptiles, crustaceans and mammals in response to pathogen infection. The last paragraph of this chapter sums up Blumberg's (2002) main points:

> Every species regulates body temperature, behaviorally or physiologically, within a range that balances the needs of a wide variety of systems, all of which are temperature-sensitive. Any change in such a fundamental variable as temperature will have far-reaching consequences; some of them will be beneficial, some detrimental.

> For hundreds of millions of years, animals have benefited from the evolutionary discovery that, regardless of the normal body temperature of a species, just a little rise in temperature for a short time increases an individual's odds of surviving an onslaught by a viral or bacterial pathogen (p. 149).

Zachary never explicitly discussed behavioral or physiological adaptations that enable thermoregulation by animals. In short, he was unable to make connections between the scientific concepts presented in class and the examples provided in *Body Heat*.

Discussion

Both social constructivist and situated cognition theorists recognize that learners use personal examples to support and take ownership of newly learned concepts (Bransford et al. 2000; Brown et al. 1989; Lave and Wenger 1991). This study demonstrates that the use of different types of examples may indicate how learners make sense of scientific conceptions. The four categories, *authentic*, *subjective*, *objective*, and *superficial* (described in our model) enabled us to categorize writers in a systematic fashion based on types of evidence that learners used to justify their position/reaction to a concept. Our findings correspond to Wallace's (2004) model, which describes that writers move along three continua, *expression*, *voice*, and *meaning,* as they integrate their everyday and scientific languages. Our propositions further elaborate on how this process might occur by defining how students make meaning of scientific concepts using everyday or academic language. When learners are *authentic*, as Wallace (2004) explained, their voice, expression, and meaning in their science writing indicates their level of conceptual understanding and how this knowledge can be applied. Christy and Betsy were described in this study as examples of *authentic* writers whose writing indicated that they were willing to use an authoritative voice to express their conceptions. In doing so, both of these writers used examples from their personal funds of knowledge, as well as from the learning context to support their claims about natural selection. In contrast, the category of *superficial* included the uninvolved student who did not participate fully in assignments yet who volunteers to be a research participant (such as Zachary). In other words, Zachary did not expand his ideas by supporting them with examples, yet he participated in the study by submitting essays and meeting us for interview sessions. Even Zachary, though, told us that he enjoyed the chance to respond to reflective writing prompts, and he volunteered to participate in interview sessions, during which he was free to express his thoughts, albeit unsubstantiated ones.

Because neither essay prompts nor the instructor indicated to students how they should defend their ideas, individuals were free to support their claims with either personal or academic experiences. The reasons why learners chose certain examples is interesting to us because it may indicate learners' levels of comfort and understanding of a concept, as well as, highlight how learners can find meaning in different ways. Every individual has his/her own funds of knowledge, so we were not surprised that writers supported their claims in their own ways. For example, Betsy supported her conceptualization of phenotype by describing *Teratornis* dinosaurs (a personal interest of hers), whereas, Steve supported his idea of phenotype by describing hair color (presented in lecture).

Learners could use whatever voice (academic or everyday) with which the felt comfortable expressing their conceptions. Hence, the essays written by participants in this study can be classified as *expressive writing*, a genre in which writers typically use

everyday language (Keys 1999). Keys (1999) explained that this form of written discourse allows writers to convey information, reflect on information and, sometimes, make connections between prior conceptions and new conceptions. We believe that a teacher's use of reflective essay prompts that allows expressive discourse sends the message to learners that the their thoughts matter and that they are free to make connections (either personal or academic) to help them to support their respective claims and propositions. Subsequently, when learners have an opportunity to respond to prompts through expressive writing the implicit message to the learner is that the teacher is a facilitator of knowledge and not an authoritative information-transmitter, a central belief of constructivist teachers (Wellington and Osborne 2001).

Social constructivism is rooted in the assumption that social interactions and communication help individuals gain and modify knowledge. Kelly et al. (2000) found that discursive practices in science classrooms gave students opportunities to not only interact with their teacher, but with each other. In their study of a third-grade teacher and her instructional strategies with her students, they found that *talking science* allowed students to explore anomalous data collected during experiments. Hence, the role of discursive teaching practices may be critical in allowing students piece ideas together (Hand et al. 2004; Norris and Phillips 2003; Wellington and Osborne 2001) in a way that allows self-talk. Engaging in self-talk as a learner learns how to use a more explanatory rhetoric falls on Wallace's (2004) *voice* continuum. In our study, reflective essays revealed instances of self-talk, such as when Ellen thought about how temperature affected her level of concentration. Self-talk was also exhibited by Jack, an authentic writer whose case study was not presented. Jack wrote, "So, I guess size really does matter. I'd like to know which critical issues arose first–size or thermoregulation? Was the morphology racing to meet the physiological needs or vice versa?" Jack was not engaged in a social dialogue with anyone, yet he engaged in asking himself questions. Self-talk may be a generative process for some learners as they negotiate different conceptions.

Although writing without talking may not be considered dialogical, the process of talking or self-reflection involves an internal dialogue that is often exposed in written discourse. By combining our analyses of both oral and written discourse allowed us to paint a fuller picture of student understanding because we used interview data to corroborate written claims. For example, in the cases of both Christy and Betsy, both learners were able to provide personal and conceptual support of ideas during the interviews, as well as, in essays. Therefore, it was not difficult to classify them as authentic learners. When explaining that both genes and the environment affect phenotype both writers supported their conceptualizations with personal examples. Betsy described her godparents' otherwise healthy daughter who was permanently disabled by a fever. Christy described how high blood pressure is influenced by both genetic predisposition and diet/activity level. This example was not discussed in the lecture or in any reading material. The instructor also categorized these essays as authentic based on the students' performances/comments made during lecture.

As learners used a more scientific expressive style, they made more authoritative claims, moving along the voice continuum of Wallace's (2004) model. In some instances writers initiated their writing with a personal voice using a vernacular expressive style but used more academic language over the period of the study. For example, by the middle of the study Steve, the objective writer, explained why gills are efficient at extracting oxygen from water. He was able to synthesize and compare respiratory strategies and support his answers with evidence from course material. As he moved along the expression continuum, so did his voice (from answering/self-talk to

explanatory). Eventually, Steve's authoritative claims increased as his understanding of natural selection developed.

When learners continue to use vernacular expression, however, and not academic language, they are still writing for a private audience and may make many non-authoritative wonderment statements (Wallace's 2004). These writers have not yet moved into a Third Space, where both the messenger and the receiver can negotiate meaning. We found that students in all four categories of our model varied in terms of how often they mentioned that they "wondered" about concepts. Even though the prompts differed, and presumably the non-directed, generic prompts gave writers the freedom to engage in self-questioning, which Bereiter and Scardamalia (1987) explained is the precursor to transformational thinking and writing, students who were more revealing of their personal connections were the ones who openly expressed their wonderment thoughts.

Levin and Wagner (2006) found that both social and metacognitive factors likely influence how writers express themselves. Similarly we found that learners were influenced by how they perceived themselves, what they perceived as expectations by the intended reader, and how they wanted to portray themselves, as Levin and Wagner (2006) described in their study. For example, one participant in our study named Katie explained in her interview that she performed on a test the way she thought the evaluator wanted her to, not according to what she thought was right. Katie was motivated to perform well in the study course and did not believe that she needed to understand evolutionary theory for her future pursuits in an allied health care profession. McLeod (1997) would argue that Katie's case points to the *teacher affect/effect*. In other words, the reality (or Third Space) of the instructor and learner are different. Learners' self-perceptions might influence discourse behavior, as well. For example, both Ellen and Jack wrote about scientists as *others*, whereas Christy and Betsy identified *with* scientists. Ellen distanced her voice and expression from that of an explanatory scientist when she wrote, "he seems very inconsiderate and talks about [anorexics] just as he talks about rats in other experiments."

Jack also used a very private, vernacular voice to express himself, "It's funny, so many scientists really think they know what they are talking about–that they 'get it'– but very few can ever create a decent analogy." Jack was a returning student who had been a filmmaker and wanted to change his profession to medicine. When we examined his writing he was not at the point of entering a Third Space to find a common meaning; however, he was a very metacognitive learner who wanted to change his learning style. "I am not 100% satisfied with [my learning strategies], but one of these days I am going to have to figure out what has to be done." Hence, Jack illustrates that personal experiences (before the course) may have influenced students' interests and skills in making personal and academic connections with newly introduced concepts within the course. From a brief analysis of student aspirations (these data were not collected as part of the original study design but were gathered as interviewees disclosed personal information), it was found that the students who were already committed to pursuing graduate studies were most likely to be authentic or objective writers, both of whom showed high cognitive affiliation. Perhaps students who have high achievement and mastery goals are more likely to be self-regulated learners who engage in authentic discourse with their peers and their teachers. We find the question of whether or not there is a correlation between writing affiliation and achievement goals an intriguing one that we think hope to pursue in future studies.

Limitations

As in any study there were limitations in this analysis of student written discourse. First and most importantly, learners self selected the essay prompts. Because we did not have a role in developing classroom activities we were not able to decide how many or which learners would respond to the two types of prompts. Secondly, this study did not focus on learning outcomes per se. We believe that a study more explicitly focused on the correlation between learning outcomes and writing affiliative style is warranted. Finally, we recognize that writers are influenced by their perception of the reading audience (Goffman 1959). Writers who are normally more authentic writers may have come across as being very objective because of their expectation from the instructor and the researchers. In addition, men and women may have disclosed different types of information (that was used to corroborate written discourse) based on their level of comfort with the interviewer or with disclosing personal reflections. Gender differences were not part of this study's focus. Finally, the instructor in this study did not provide any written feedback to students on their essays. She only responded to the collective ideas that she read. For writing to be a more generative process learners should be able to reflect on their written discourse and modify it and they generate meaning. We recognize the limitation of the design of this study.

We recognize that some participants may have felt more comfortable disclosing personal information to the instructor and the researchers. Witz et al. (2001) described the importance of developing:

> A personal subjective understanding of the phenomenon of interest in different individuals by way of sustained attempts to share, empathetically and sympathetically, the individual's feeling, state of mind and past experience, both during interview and in many re-hearing of the tapes afterwards (p. 198).

Christy and Betsy may have responded to a sense of empathy displayed by the interviewer and the instructor, and as a result, were willing to disclose personal information. McLeod (1997) posited that instructors have much control in how students write and shift their beliefs in their own understanding based on affective interactions (verbal or written comments). She described the "Pygmalion effect" (when students improve because of positive interactions with their instructors) and the "Golem effect" (when students performance decreases because of negative interactions with instructors).

Implications

This study is significant for three main reasons: (1) it reinforces the importance of reflective writing in college science classes; (2) it provides a deeper look into how college students make meaning of science concepts; and (3) it informs instruction in science classes by helping instructors understand how writing can help students make meaning of abstract concepts.

Reflective writing is important for learning

First, opportunities to write expressively and reflectively allow students to examine their own understanding and be more metacognitive (Levin and Wagner 2006). Because writing is an iterative, back-and-forth process learners must consider what they know before they document their thoughts (Flower and Hayes 1980). This study demonstrates that learners

benefited from expressing their ideas in reflective essays by admitting which concepts they felt they understood and those with which they were still fuzzy. Interviews with study participants and their instructor then confirmed that writing allowed the learners to consider what they knew, what they did not think they knew, and whether they felt they needed to learn more to understand the concepts. Reflective writing assignments may provide the opportunities needed for learners to piece together prior and newly gained knowledge. We also suggest that learners might need to write multiple iterations of their reflective essays in order to engage in self-talk and modify their thoughts, as the Bereiter and Scardamalia (1987) and Flower and Hayes (1980) models support. Although writing exercises have been promoted in K12 classes, we argue that writing can play an important role in college science classes as students make sense of abstract concepts.

Second, being able to use a vernacular voice allowed students to express their own thoughts. Not all students enter science classrooms comfortable or fluent in academic voice. (Wallace 2004), and the instructor in this study recognized this fact. The instructor, in fact, insisted that some students knew the concepts but used "sloppy wording," which meant that she did not feel that those students had mastered how to use scientifically-accepted language (Balgopal et al. 2006). However, by assigning reflective writing assignments she gave all students a voice, whether they used vernacular or academic language. Students contributed to the shared discourse space by sharing their thoughts with the instructor. She could refer to patterns in student writing (such as word choice or potential misconceptions) in her lectures/class discussions. It is very likely that the instructor would have been unaware of the extent of her students' ideas had she not assigned and read their essays throughout the semester.

Third, a shared conversation can promote a shared sense of practice and purpose if students feel that they are seen as individuals whose input affects the group's performance (Lemke 2001; Lim and Barton 2006). We certainly found that participants enjoyed being able to write reflective essays in this course. During interviews with participants none of the 19 objected to the writing assignments. We believe that if learners feel comfortable voicing their ideas and conceptions in a shared space, they may be able to make meaning of science concepts, just as some our participants explained they did by meeting with peers during writing sessions. Writing can, therefore, play a valuable role in college science courses (many in which students do not feel that they have a voice) because they feel that they have a chance to directly communicate with the instructor. Most of the participants in our study also stated that they would have preferred specific feedback on their essays rather than a general response during a subsequent class period. The instructor chose not to respond to each of the 75 students' 10 essays because it was the first time she had used writing assignments and did not know what to expect. Since this study was conducted she has continued to use reflective essay writing in all of her biology courses and provides individual feedback to all of her students.

Meaning making is better understood

Reflective writing can play an important role in which learners make meaning of science concepts. Wallace (2004) described in her model the *process* writers take as they begin to use more scientifically authentic language, while Levin and Wagner (2006) identified different *dimensions* of written discourse, as well as how writers perceived writing. Grounded in both of these theoretical papers, our study sheds light on how learners make meaning (in sometimes authentic ways) by making cognitive or affective connections to concepts. We posit that learners who are able to make multiple connections with concepts

(both cognitive and affective) are most likely to understand the abstract concepts being presented in class because they are able to leave the private and vernacular voice and venture out into a Third Space where they can construct meaning in a dialogical context. Social constructivism purports that learning and making sense of concepts occurs in a social context; our study specifically identifies (and categorizes) the types of evidence that learners use from their social worlds as they learn about abstract concepts, such as natural selection.

Because learners draw on experiences and emotions triggered by learning environments to support their conceptualizations it is important to consider the role that the learning environment plays on learning too (Brown et al. 1989). If class discussions involved emotional debates and arguments, we would expect that learners' positions and responses would emerge in their written discourse. Hence, reflective writing, for which prompts can be triggered by class discussions, readings, or inquiry activities, takes into account any shared discourse that is generated in the learning environment.

Informs writing instruction

The role of teaching strategies that model for students how to find evidence supporting their conceptual understanding is critical in allowing students piece ideas together (Wellington and Osborne 2001). Understanding that learners need to draw on both personal and academic funds of knowledge and also need to feel free to express both their cognitive and emotional responses to concepts, instructors can design writing activities that give learners "room" to do so. Balgopal and Wallace (2009) using the findings from Balgopal (2007) found that instructor-guided in-class writing activities in college biology courses enabled students to move from *superficial* or *subjective* categories to *authentic*. Education students enrolled in a biology course were asked to write several iterations of reflective essays that initially focused on what students learned and knew about hypoxia (an ecological crisis) from a series of journal readings. Then, students were asked to reflect on their thoughts about hypoxia and to consider how others (farmer, Gulf Coast fisherman, homeowner) might react. In these essays students often drew on their personal experiences and were uninhibited to expand their essays. The third iteration of the essay required that students describe a dilemma based on what they (a) knew and (b) felt about hypoxia, followed by an explanation of how the writer might (c) act to resolve the dilemma. The third essay tended to fall into the persuasive writing genre and revealed whether students had a strong conceptual understanding of the ecological principles underlying the hypoxia issue. The students who could not only reveal a strong understanding of the concepts, but could draw on personal funds of knowledge were labeled as *authentic*. Students who could only define hypoxia without describing how their personal behaviors could affect hypoxia, were labeled *objective*, whereas those who only provide emotional and personal responses (such as, "this is a horrible situation" or "I don't think it's fair to blame the farmers!") yet could not demonstrate any scientific understanding of the concept were labeled *subjective*. Balgopal and Wallace found that by guiding students in the prompts that 2/3 of the class moved from at least one category closer to authentic of which half moved 2 categories (e.g., *subjective* to *objective* to *authentic*). One question that the findings of Balgopal and Wallace (2009) beg is whether or not students who presented *authentic* persuasive arguments felt compelled to review their cognitive and affective connections beforehand. These data were not collected in the described study.

In a subsequent study Balgopal et al. (2009) tested the CAAM model on Education students, but expanded it to students enrolled in a tribal community college, and to

Biology majors at a 4-year college. They found that tribal college students were much more likely to begin writing in the *affective* category and that the Biology majors were more likely to begin writing in the *objective* category. With guided writing prompts and in-class discussions, half of the students in this study were able to become more *authentic* writers. Balgopal et al. (2009) encouraged science educators to construct writing prompts and in-class activities that were most meaningful for each population of learners. We argue that, in general, that studies that specifically address scaffolding efforts of the teacher and how it affects students' abilities to make connections in college biology courses are still needed.

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Appendix A: Reflective essay directed prompts

1. In class your instructor stated that natural selection acts on phenotypes. How would you explain this statement as it relates to the following scenario? There are two populations of chickens: population A lives solely in a coop, has limited opportunity to move, and is provided with unlimited food (chicken chow). These birds are unable to fly well and produce large eggs with large yolks. Population B lives freely on a farm, has plenty of opportunity to fly and forage for natural food sources, in addition to being provided daily with chicken chow. These birds produce small eggs with small yolks.
   If a free- range farm chicken were moved to a coop, what type of offspring would it produce? If a coop chicken were moved to a farm, what type of offspring would it produce? Please explain your answer by discussing phenotypes and natural selection.
2. Hyenas are known for being aggressive, competitive scavengers.
   a. How would you design an experiment to test whether this behavior is genetically or culturally inherited or both?
   b. How would you use the following statement to justify your rationale "Genes + Environment affect Phenotype?"
   c. Does natural selection act on culturally inherited traits, genetically-inherited traits or both. Explain how this occurs.
3. Among species there is a positive allometric relationship between body size and metabolism. However, within one species there might be a negative relationship.
   a. Explain why you might observe this relationship (i.e., how might individuals within one population of one species differ from one another?).
   b. Choose any organism and give 2–3 examples of possible phenotypic traits that may contribute to a negative relationship within species.
4. Your instructor described the snail kite, limpkin, and apple snail scenario in class. She explained that the snail kite prefers light colored snails because it uses visual cues for foraging, whereas the limpkin prefers larger snails because it used tactile cues for foraging. She also explained that there is a great amount of variation in phenotype of the snails.

a. In an environment with just snail kites what type of snails would you expect and why?
b. In an environment with just limpkins what type of snails would you expect and why?
c. In an environment without any predatory birds, what type of snails would you expect and why?
d. Briefly explain the importance of variation in the process of natural selection.
e. Briefly explain whether the snails can choose or control their phenotype.

5. Following are related questions and statements taken from previous responses

a. Is this statement scientifically accurate? Please explain in depth
b. If this statement is incorrect, is it because the concept expressed is wrong or because it is worded poorly? Please explain
c. If the statement is inaccurate, please rewrite it so it reads scientifically correct (note: there are numerous right answers)
d. Often we use anthropomorphic (ascribing human characteristics) language to describe non-human entities. Did any of these statements use such language and how?

Statement #1: "An animal changes its appearance to help it survive."
Statement #2: "The environment acts on genes by encouraging them or by selecting them out."
Statement #3: "Due to natural selection the beneficial genes will progressively grow."

6. Natural selection acts on phenotype, which is determined by genotypic and environmental interactions. Although natural selection acts on individuals, evolutionary changes are observed at a population level. Evolution can be defined as changes in gene frequencies within a population between each generation. "

a. Does this passage make sense to you? Please restate it in your own words.
b. Do you agree with this passage? Please explain why or why not.
c. Give at least one example from your physiological ecology notes (from this class) to justify why or why not you agree with this passage (i.e., use a specific example of adaptation to explain the concepts described in the passage.).

7. In shoreline environments where tide levels vary daily, aquatic organisms are exposed to low tide (during which they are exposed to air) and high tide (during which they are under water) and they employ different respiratory strategies.

a. Why might it be evolutionarily advantageous for high shore gastropods, such as limpets (that have a gill), to reduce their metabolic rate significantly? When they are under water they use their gill as the primary respiratory organ and when they are exposed to air they use diffusion across the surface of their tissue (mantel).
b. Similarly, why might it be evolutionarily advantageous for blue crabs (also use gills) to be able to elevate its heart rate by up to 200% during aerial exposure?
c. Explain why you think it is important that different species have evolved different respiratory strategies to cope with the same environment.

8. In class on November 8 your instructor asked you what unifying themes of all of the topics described so far in physiological ecology stood out to you. The list you generated included the following:

Maximizing effeciency
Maintaining homeostasis
Endothermic vs. ectothermic animal life cycle comparisons
Phenotypic adaptations
Energy constraints

This list is not exhaustive of possible themes, so there may be others that you can think of that have not been included here. Please pick one theme (listed or one that you come up with) and justify why that theme unifies all the topics that your instructor has discussed in Physiological Ecology so far.

9. Many types of animals that live in aquatic environments have evolved different physiological, behavioral and physical adaptations allowing them to cope with the conditions.
    a. Name and explain two physiological respiratory adaptations of aquatic animals that enable them to survive in their environment as your instructor has described (or that you have read about).
    b. Explain how taxonomically very unrelated organisms may have evolved similar strategies to cope with the similar aquatic environments (for example, insects and birds have both evolved wings, although these organisms do not share a common winged ancestor).
10. Please answer the following questions honestly
    a. How did the process of answering email reflection questions help you determine which concepts you knew well or were confused about? If you can, please give examples of concepts that you realized you understood or those that you were confused about.
    b. Before taking this course what was your normal method of studying?
    c. How has your studying (preparing for exams) changed during the course of physiological ecology?
    d. How has your learning (connecting new knowledge to prior knowledge) changed after doing weekly email reflections?
    e. Are you comfortable with your understanding of natural selection and adaptations (physical, behavioral and physiological) now at the end of the semester?
    f. Do you feel like you have a better understanding now at the end of the semester compared to your understanding prior to taking this course? If yes, what helped you most? If no, what would have helped you?

Appendix B: Questions used in semi-structured interviews with research participants

Interviews 1 and 3

1. Please explain what answer you provided on the CINS diagnostic test
2. How did you arrive at this answer?
3. Do you feel comfortable with your answer? Why or why not?
4. How has the act of interviewing influenced your understanding of natural selection?

5. How has the act of writing reflective essays influenced your understanding of natural selection?
6. Can you describe anything about the learning environment that has influenced your learning of natural selection?

Interview 2

Question A

Students were presented 3 boxes of insects (ladybird beetles, tiger moths, and red-spotted purples) that are highly variable within each population.

1. Can you describe to me what you see in each of these boxes?
2. How would your answer change if I tell you that all the individuals are of the same species and were part of the same population?
3. Could you please describe to me, to the best of your knowledge, what a species is?
4. Why do you think that these differences (variation) between individuals in a population are important for the evolutionary success of this species?
5. Are differences within a population limited to physical characteristics?

Question B

Students examined a data table of parasitic wasp fitness correlates (head capsule width, longevity, lifetime fecundity, and survivorship of offspring to adulthood).

1. Can you describe to me what these data mean?
2. These are real data from a study on wasps and these are fitness correlates. Can you tell me what fitness means?
3. How do these (presented data) measurable traits affect fitness?
4. [if the topic comes up, ask students to define viable and fertile and fecund].

Question C

Students were given blank paper and colored pencils or markers and were given the opportunity to use these materials to answer the following questions.

1. So far we have discussed how individual animals may differ in a population, and that some traits may be associated with the individual animal's fitness, but how do these differences arise?
2. When are these variations arising?
3. Are these variations being passed to offspring? If yes, how does this occur?

Question D

For students who are concurrently answering directed reflections.

1. Are you satisfied with your understanding of evolutionary adaptations? [If no, then ask why and what alternative ideas that they think might make sense]

2. How has your understanding of evolutionary adaptations been affected by the instructors' ecology course?
3. Has the activity of writing a weekly email reflection question, influenced your understanding of adaptation in any way at all?

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