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Epistemic Complexity in Adolescent Science Writing

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Abstract: Increasing attention has been paid in recent years to the ways writing may engage adolescents in higher levels of epistemic complexity (i.e., postulating causes, reasons and other relations or theories related to scientific phenomena), yet in secondary science classrooms, writing has primarily been used for assessing students' content knowledge. Embedded in a larger national study of secondary writing in the United States, this study investigated the qualities of science writing samples collected from 33 adolescents attending schools identified for exemplary writing performance. We asked: How is epistemic complexity reflected in adolescents' writing?; How does the level of epistemic complexity differ by adolescents' language background, grade level, and school context?; What is the nature of the relationship of types of writing and higher or lower levels of epistemic complexity? We found the majority of writing adolescents produced did not show evidence of high levels of epistemic complexity. Notable exceptions were reading reflections and lab reports. Implications for adolescent science writing instruction are discussed in light of higher standards for disciplinary writing in secondary schools.

Keywords: Adolescent writing; science writing; epistemic complexity; English learners

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A growing body of literature highlights the importance of writing in the development of 21st-century dispositions and skills that involve reorganizing and generating new knowledge (Chuy, Scardamalia, & Bereiter, 2012;). However, while a number of scholars have provided a convincing case for how writing competence is fundamental to fostering these 21st Century dispositions and skills (Hand, Lawrence, & Yore, 2010; MacArthur, Graham, & Fitzgerald, 2008; Moje, 2011; Norris & Phillips, 2003 , as several recent studies have shown, secondary level science teachers typically pay little attention to writing or to the potential different kinds of writing tasks might offer forstudents' development of both writing competencies and content knowledge (Rijlaarsdam, Couzijn, Janssen, Braaksma, & Kieft, 2006; Wellington & Osborne, 2001). Furthermore, as Pearson et al. found (2010) many secondary science teachers see reading and writing as universal skills that are developed elsewhere (namely in English Language Arts classrooms) and do not understand how to use writing to teach their adolescent students the unique ways thatmeaning is communicated in the scientific community.

This scenario is changing however. In the United States, the Common Core State Standards (CCSS) for literacy (adopted by the majority of states) emphasize writing in the core disciplines – including science (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010). Specifically, the CCSS stress developing students' abilities to examine and convey complex ideas clearly and accurately, produce writing appropriate to different purposes and audiences, and draw evidence from sources to support claims (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010). In addition, the recently published Next Generation Science Standards (NGSS) require students to engage in the practice of "obtaining, evaluating and communicating information" (Achieve, 2012). Both the CCSS and the NGSS mark a shift in the emphasis being placed on disciplinary writing and highlight what some studies on writing in secondary science classrooms have suggested: writing is an important, perhaps critical, component of learning to "do" science and think like a scientist (Hand & Prain, 2002; Metz, 2006; Porter et al., 2010).

In science, providing a claim and evidence of a claim, for example, represents a particular way of knowing (i.e., epistemology). However, to what extent science teachers and their students understand the relationships of what they write and how they write to the work of scientists in reorganizing and generating knowledge has come under question. Scholars such as Prain and Hand (1999) have noted students oftentimes demonstrate a "limited capacity to explain how knowledge claims are established in science in relation to learning through writing, or to understand how writing could act as an epistemological tool" (p. 160). These findings suggest that students need more support in engaging in writing that can function as an instrument for knowledge reorganization and generation as in and through these writing activities the epistemologies undergirding scientific disciplines become enacted. The concept of epistemic complexity becomes salient here.

Since we were interested in the qualities of writing adolescent students were producing in their science classes with a particular concern for ways scientific knowledge was being represented in their written work, we turned to the concept of epistemic complexity following the work of Hakkarainen (1998, 2003) and Zhang et al. (2007). In this vein of inquiry, epistemic complexity provides a way to characterize how writing functions as an instrument for knowledge representation. Epistemic complexity isa tool to measure the extent to which a writer explains phenomena, postulates causes, reasons and other relations or theories related to scientific phenomena (Hakkaranien, 2003; Kelly & Takao, 2002; Kuhn, 1993; Salmon, 1984). Epistemic complexity can be measuredon a scale from simple descriptions of scientific phenomena to increasingly more complex explanations of relationships of phenomena and analyses of phenomena that include arguments with claims and counterclaims, supporting evidence and warrants.

In sum, although the CCSS and NGSS raise expectations for writing in American secondary science classrooms, what kinds of writing adolescents should be expected to do in order to align to these standards is less clear. In an effort to explore this concern empirically, the study reported here sought to (1) characterize the extent to which adolescents' writing exhibited high levels of epistemic complexity (i.e., writing involving postulating causes, reasons and other relations or theories related to scientific phenomena), (2) determine whether the writing of students of different language backgrounds, grade levels, and school contexts differed with regard to levels of epistemic complexity evident in their writing, and (3) characterize the types of writing that exhibited higher levels of epistemic complexity. We pursued these questions in order to inform future research and efforts to improve the teaching of science writing in secondary school classrooms.

1. Science Discourse: Its Characteristics and Epistemological Foundations

The goal of science education may be considered twofold: not only mastery of scientific content and concepts but also learning how to engage in scientific discourse as to represent and generate new knowledge as expert scientists do (Bricker & Bell, 2009). In this section we examine the literature establishing how knowledge representation and generation is viewed in the scientific domain.

Descriptions of observable phenomena and explanations of theory are common elements of scientific discourse (Kuhn, 2010, Rijlaarsdam et. al., 2006). However, teaching students to describe phenomena and explain theory without knowledge of how they are related to each other is problematic for a variety of reasons. As Kuhn et al. (2008) explain, contemporary science education emphasizes the importance of developing scientific reasoning skills as well. Theoretically, through the development of reasoning skills, students would learn to clarify and reorganize their understandings of scientific phenomena and theories and thus enhance their understandings of them.

While doing this work, they will also deepen their understandings of the epistemological foundations of science.

Learning to engage in discourse that involves scientific reasoning requires learners to not only describe phenomena or explain a theory but also connect pieces of information and describe causal relationships (Hempel, 1965; Salmon, 1978). To do so, as Salmon (1978) asserts, advanced science discourse goes beyond mere description and explanation as it embraces two powerful processes. First, explanation of a phenomenon "…essentially involves locating and identifying its cause or causes" (p. 685). Causal relationships are typically established directly from observation in various contexts rather than a single one and in turn these observations are likely to generate the second process—"subsumption under law" (p. 685). On a higher cognitive plane, general law arises from theoretical science which not only explains a concrete/observable phenomenon or theory, but also predicts what may happen under a specific situation and the possibility of some outcome or alternative. As scientists articulate these cause-effect sequences and their potential outcomes, they engage in reorganizing and generating new knowledge. For science learners, engaging in writing that requires articulations that go beyond mere descriptions of phenomena or theories can afford them the opportunity to comprehend and elaborate the hidden theoretical mechanisms of the material world, and thus, reorganize and generate science knowledge.

In a synthesis of research examining epistemological understanding in science, Kuhn et al. (2000) posit that there are four levels (i.e., realist, absolutist, multiplist, and evaluativist) moving from subjective understanding in the immature learner through a balance of objective and subjective understanding in the more mature learner. A realist perspective does not involve critical thinking, yet the evaluativist is characterized by seeing knowledge as something generated by human minds which may be uncertain, requiring judgments that promote and even require sound assertions. Applying these levels to a study of learners ranging from elementary school through adult, the authors concluded that "reasoned argument is worthwhile and the most productive path to knowledge" (p.325).

While some scholars note that engaging younger learners in higher-order critical reasoning is difficult and oftentimes not addressed explicitly in coursework (Duschl, 2008; Sandoval, 2005), adolescents can learn the complex cognitive processes of scientific discourse throughexplicit instruction in claim and counterclaim—both supported by evidence through argument and dialogue (Kuhn et al, 2009). Building on earlier research establishing that instructional emphasis on explanation may conflict with students' attention to the importance of evidence in justifying claims and observations (see, for example, Brem & Rips, 2000; Kuhn 1993), Kuhn and Crowell (2011) tested an intervention in which students were taught to engage in argumentation, explicitly being instructed in the skills and importance of claims and counterclaims justified with evidence. Findings suggested that students who engaged in dialogic argumentation demonstrated a higher quality of scientific reasoning in addition to greater awareness of the relevance of evidence to argument in scientific discourse. The authors concluded that the dialogic method of argumentation is valid for developing the cognitive skills required for scientific reasoning.

Research on the teaching of argument as a central component to how knowledge is constructed in the scientific community has been of particular interest to some scholars in the past couple of decades (Bicker &Brell, 2009). For example, the Toulman Argument Pattern (TAP) has been investigated with regard to how it might assist students in understanding scientific constructs and for assessing the quality of their written argumentation (Osborne et al., 2004). Building on Toulman's emphasis on warrants and claims in science writing, Konstantinidou and Macagno (2013) theorized that argumentation schemes can be used for helping students analyze, reconstruct, and improve their reasoning skills, particularly as they adjust new understanding to connect with prior knowledge on a specific issue. The authors note that argumentation schemes are particularly applicable to science education in a two-step process. First, an argument is analyzed with the claims supporting the conclusion, and, second, constructing an argument requires that links to evidence and prior knowledge are identified, retrieved, and defined. In this multi-step process, "the student is requested to analyze and reflect on the notions underlying his reasoning about a specific scientific phenomenon" (p.1085).

This body of scholarship highlights that both explanation and argumentation are essential elements of how scientific knowledge is expressed, and that teaching students to engage in writing that requires these actions also involves engaging in the kinds of complex reasoning activities used by more expert scientists. As the studies highlighted here suggest, some kinds of writing activities have the potential to help students understand both what constitutes scientific understanding as well as develop the dispositions and skills to engage in advanced scientific discourse grounded in deep epistemological understandings.

1.1 The Nature of Science Writing Taught in Secondary School

How well do the types of writing adolescents create advance these deeper epistemological understandings and align with developing 21st Century dispositions and skills in science as described in the CCSS and the NGSS? The relevant literature in this area is dominated by a focus on one particular type of writing: the laboratory report. The lab report has been of concern to researchers as it is a common type of writing required of secondary- and post-secondary-level students and essentially provides an outline for a particular technique, approach, and reasoning process called the scientific method. In one study of eighth grade students' experiences with writing lab reports, Keys (1998) revealed that although students generated hypotheses, examined patterns in data, and made general knowledge claims in response to the task of a lab report as they were explicitly instructed to do, the fixed structure of the task also constrained students' deep thinking into scientific problems. The aforementioned finding is problematic since as discussed in a report commissioned by the National Academy of the Sciences and the National Science Foundation, one of the purposes of the laboratory experiment is to promote an understanding of the complexity and ambiguity of scientific knowledge – or what aligns to the earlier-mentioned "evaluativist" perspective (Singer, Hilton, & Schweingruber, 2006).

With an interest in the potential of offering scaffolded writing tasks in prompting students to engage in more complex thinking in their writing, Hand, Wallace, and Yang (2004) sought to identify the outcomes of infusing 7th grade science laboratory instruction with science writing heuristics (prompting students to ask such questions as "what are my questions?", "what did I do?", "what did I see?", "what can I claim?"). The results of their analysis of students' retrospective accounts of writing in response to these questions as part of their laboratory report task suggest that such an approach positively impacted students' understandings of the rhetorical features of a scientific claim and argument and that such writing enhanced their learning of the science content. This research draws attention to the potential for such heuristics to encourage better writing and deeper thinking about scientific content in contrast to the less promising, standard lab report assignment.

The body of research we have explored here illustrates that writing in science can foster both higher levels of scientific reasoning and understanding of content. However, outside the study of which this one is part very few researchers have investigatedthe qualities of secondary school students' science writing in a variety of school contexts and among students in different grade levels and from different language backgrounds. Further, no other studies have investigated the writing of adolescents in schools with histories of exemplary writing performance as to provide potential exemplars of adolescent writing that align with the higher standards for disciplinary writing as described in the CCSS and NGSS (Nachowitz, 2013) .

1.2 Theoretical Framework

Sociocultural theory provides a lens through which we may deepen our understanding of scientific writing and the contexts that produce varying levels of epistemic complexity in student writing. A growing body of literature has focused on investigating science education from a sociocultural perspective (Green & Dixon, 1993; Jimenez-Aleixandre et al., 2000; Kelly & Bazerman, 2003; Kelly, Chen, & Crawford, 1998; Kelly & Crawford, 1997; Lemke, 1990). By adopting methods including ethnography, discourse analysis, ethnomethodology, and others these studies understand that learning science is a sociocultural activity where disciplinary knowledge is constructed in a community culture through a variety of oral, aural, visual, and written activities. This perspective views members of the scientific community as ascribing meaning to the processes, artifacts, practices, and signs and symbols that they construct in and through their activities and in discourse traditions that have developed over time and oftentimes in unique ways.

Discourse plays an important role in socializing learners into a disciplinary community. As Lemke (1990) explained, speaking, writing, drawing, calculating, and experimenting, are conduits through which the "conceptual systems" and the "scientific theories" are taught and learned. Thus, science writing (along with other forms of discourse), from a sociocultural perspective, is seen as a potentially powerful activity for developing understandings of the epistemological foundations of science. Conceiving of science as a "special way of talking about some set of topics" (Lemke, 1990, p. 155) connects the learning of science to learning the particular uses of scientific language. Mastering scientific discourse in ways that allow for generation of new knowledge involves more than describing content, concepts, or theories, as Lemke explained, "it is a matter of the ways these special words are used together, the semantic relations we construct among them when we use them" (p. 155).

In alignment with a sociocultural framing that takes into account the ways discourse reflects and is embedded in the development of complex ways of understanding science and generating new scientific knowledge, we investigated the following research questions: (1) How is epistemic complexity reflected in adolescents' writing?; (2) How does the level of epistemic complexity differ by adolescents' language background, grade level, and educational context?; and (3) What is the nature of the relationship of types of writing and higher or lower levels of epistemic complexity?

2. Method

The current mixed-method study was embedded in a National Study of Writing Instruction which researched the teaching and learning of writing in middle and high school settings across the United States. The national study aimed, in large part, to track changes in approaches to writing instruction from a study conducted in 1981 (Applebee), and to investigate the extent to which student characteristics (e.g., achievement histories, grade level, language background) and school contexts relate to different writing experiences and outcomes.

2.1 The Larger Study Sample

Criteria used to identify the sample for the larger study included (1) diversity in state requirements for writing and (2) schools' histories of performance in writing. With regard to diversity in state contexts, the larger study sought to include states that had different requirements for writing in their high stakes, exit-level assessments; California, Kentucky, Michigan, New York, and Texas were chosen for this reason. Within this sample, New York was the only state that required writing of a paragraph or more in science and mathematics on the secondary exit exam. Kentucky offered the option to include science writing as part of a portfolio assessment and other states included writing in English Language Arts only, and each state with slightly different emphases in genres expected. Second, since one of the objectives of the larger study was to investigate potentially better-case scenarios for secondary level writing, schools with histories of exemplary writing performance on exit-level exams that were also nominated by leaders in the field of English as having traditions of excellence in the teachingof writing were considered for inclusion. Unlike traditional corpus studies that seek to attain a representative sample of writing, the intent of this sampling method was to highlight writing produced in a variety of diverse, yet unique schools in terms of being characterized as historically exemplary in English Language Arts performance.

2.2 Current Study Sample

Because one of our interests was in the experiences of both native English speaking and English learner students, of the five states included in the larger study, this study drew on data collected in the three most linguistically diverse states: New York, California, and Texas. Both Michigan and Kentucky were eliminated from the current study since the sample of students from those states did not include both native English speaking and English learner participants in all of the grade levels of interest (6th, 8th, 10th, and 12th). Therefore, while the larger study included 14 students from California, 20 from New York, and 36 from Texas, we selected 11 students from each of the three states, totaling 33 students on which to focus our analyses. This purposive sample took into account the following criteria: the total number of pieces of writing from students in the current study was representative of the total number of pieces of writing produced by students in the larger sample, inclusion of all target grade levels (i.e., 6th, 8th, 10th, and 12th), both native English speakers (NES) and English learners (ELs), and both males and females (see Table 1).

The schools these students attended varied in size and demography as can be seen in Appendix A. Of these schools, several had support from school administration in implementing writing across the curriculum programs (e.g., Albert Leonard in New York) and others had faculty with strong ties to the National Writing Project which provided ongoing support for the development of teachers' writing pedagogy (e.g., King Drew in California). Two schools stood out from the others in the extent of their ties with external, teacher professional development: King Drew High School in California, a magnet school with a science and health theme had particularly close and ongoing ties with the University of California Los Angeles (UCLA) Writing Project. Grisham Middle School, like all the schools in the Austin Unified School District, had extensive support from the local Math/Science Collaborative run by the local university and featured extensive and ongoing faculty training in teaching laboratory report writing from grades one through twelve.

Table 1. Participant Characteristics

School	State	Grade	Pseudonym	Language Background	Total
Montebello	CA	6	Alissa	EL	5
		8	Angel	EL	1
		8	Emily	EL	6
		6	Lisa	NES	3
John Adams	CA	8	John	NES	1
King Drew	CA	12	Bob Bill	NES	5
		10	Kobe	NES	20
		12	Paris	NES	14
		10	Sunny	EL	22
		12	Guitar player	EL	1
		10	Arial	NES	13
Grisham	TX	8	G6	EL	5
		6	G7	NES	14
		8	G2	EL	6
		6	G8	NES	17
Spring Branch	TX	8	SB8	NES	4
		6	SB5	EL	32
		8	SB12	NES	1
McCallum	TX	10	M3	NES	10
		10	M1	EL	3
Round Rock	TX	12	RR6	EL	8
		12	RR1	NES	10
Albert Leonard	NY	8	Betty	NES	21
		6	LouAnn	NES	1
Port Chester	NY	8	Yasmine	EL	6
		6	Tony	EL	2
		8	Karen	NES	5
Batavia	NY	12	Don	NES	11
		10	Randy	NES	9
		10	Dave	NES	10
		10	Chin	EL	27
New Paltz	NY	10	Shane	EL	9
		12	Shanice	EL	2

2.3 Data Collection

The 33 students in this study produced 304 pieces of writing in their science classes over an approximately 13 week term (half of a school year). This writing included worksheets, short- answer responses, and class notes as well as more extended writing such as lab reports. Collection procedures were adapted to the particular relationships at each school site. In some cases the on-site coordinator collected the work from subject-area teachers on a regular schedule; in others, the focal students brought their work individually to the on-site coordinator for forwarding to the research team. In either case, the originals were returned to the students and copies forwarded on a regular basis to the field researchers. As data were received at the research center, they were inventoried by staff and entered into SPSS as described below and in further detail in the larger study methods and procedures document available online (Applebee & Langer, 2011).

2.4 Data Analysis

Our procedure for the analysis of students' written work was four-fold. To begin, the students' writing was first categorized by type based upon Applebee's 1981 study which framed the larger national study of which this one is part. Types were defined as mechanical, informational, personal, and imaginative (see Appendix B). Next, based on hierarchies for epistemic complexity used in previous studies (e.g., Hakkarainen, 1998; Webb, 2002), one of the research team members coded the 304 pieces of writing on a five-point scale with writing at the lowest level (i.e., level one) showing evidence of separated pieces of information, and writing at the highest level showing evidence of postulating causes, reasons and other relations or theories related to scientific content. The two highest levels (four and five) are where explanations of phenomena that might include arguments with claims and counterclaims, supporting evidence and warrants are evidenced. The categories of epistemic complexity we used in this analysis, which are slightly modified from those used by other researchers, are defined in Table 2.

Table 2. Levels of Epistemic Complexity

Level	Definition
1	Separated pieces of facts. A statement consisting of a list or table of facts with hardly any integration or connections.
2	Partially-organized facts. A statement consisting of facts that were loosely organized together. The facts were stated without relating them to each other by means of causal or some other connections. Only a minimal amount of inference seemed to be involved.
3	Well-organized facts. A statement consisting of rather well-organized factual or descriptive information. Although the ideas did not explicitly provide an explanation, it was meaningfully organized and had a potential of facilitating understanding of the issue in question.
4	Partial explanation. A statement represents an explicit attempt to construct an explanation and to provide new information, but the explanation was only partially articulated. It was only an explanatory sketch that was not further elaborated.
5	Well organized explanation. A statement containing postulations of common causes, reasons and other explanatory relations, or theoretical entities.

Of all of the written work, 17.4 % could not be categorized on the epistemic scale because these pieces were not legible or they were selected-response items such as multiple choice or matching exercises that did not require students to compose language that could be analyzed using the scale of epistemic complexity.

In the next stage of analysis, we used a concept-mapping procedure that was originally constructed by Chi et al. (1981), and was employed to represent semantic node-link networks of key terms (see Appendix C). Proceeding from Chi et al., Fellows (1994) adapted a concept-mapping approach to transform students' writing into representations of their structure through tracking essential ideas and relationships among these ideas. Similar to Chi et al. and Fellows (1994), we employed concept-mapping to transform students' writing into visual representations of their structure. Two types of nodes were identified in this process, and they are: a) entity (i.e., the key concept(s) in a statement- indicated by circles); and b) relationship (i.e., the association between/among different entities- indicated by diamonds). As can be seen in Figure 1, the following excerpt from a student's work was level 2 characterized by two or m entities that had only one layer of relationship. For example, the following excerpt was indexed at Level 2: Partially-organized facts:

> Dermal bones form in subcutaneous membranes. They're mostly composed of cancellous[sic], bone and parts of irregular bones. (Student 1)

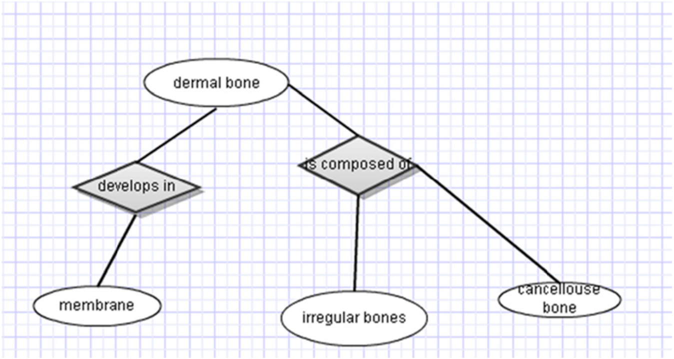


Figure 1. *Example of level 2: Partially organized facts*

To establish reliability of the coding procedures used in the study, two university teachers in the Department of Education independently coded 20% of the written samples (randomly selected) (Zhang, Scardamalia, Reeve, Messina, 2009). We used Cohen's Kappa to calculate the inter-rater agreement for each pair of raters, and then took the average of Kappa across all pairs of raters (Griffin, 2011), resulting in an inter-rater reliability of 0.89 (SE = 0.02).

To further examine the patterns of epistemic complexity and answer our second research question, we used a one-way ANOVA to test the statistical significance with regard to students' language background, grade level, and school context

acknowledging that the statistical power of such a test on such a small sample is weak. The unit of analysis is participant (n=33), whose level of epistemic complexity (EC) was defined as dependent variable, and language background (LAG), grade level (grade), and school context (STA) were independent variables. Each participant's level of epistemic complexity (EC) was calculated as a weighted average, as the number was the number of written items in a level, and the weight was the level of epistemic complexity (1-5). For example, if a student produced 6 items at level 1, 5 items at level 2, 20 items at level 3, 1 item at level 4, and 2 items at level 5, then his weighted average of the level of epistemic complexity is:
$(6*1+5*2+20*3+1*4+2*5)/(6+5+20+1+2)=2.65$.

In our sample, five students had fewer than 2 pieces of writing; therefore, we ran the ANOVA tests again to exclude the 5 students and compared the results with the larger sample. We also used SPSS to examine whether there was a normal distribution across the data set, and results showed that the data met the assumptions of ANOVA (data were normally distributed).

Finally, once we identified patterns of epistemic complexity across the writing of students with different language backgrounds, grades, and school contexts, we crafted descriptive illustrative cases of epistemic complexity (Yin, 2005).

3. Findings

In response to our first research question (How is epistemic complexity reflected in adolescents' writing?), we found that little of the writing in our sample from schools with histories of exemplary performance in writing represented higher levels of epistemic complexity. Overall, the average level of epistemic complexity in students' writing was 1.7 (between separated pieces of facts and partially organized facts) on the scale (Level 1: Separated pieces of facts; Level 2: Partially-organized facts; Level 3: Well-organized facts' Level 4: Partial explanation; Level 5: Well organized explanation).

We used the categories of mechanical, informational, personal, and imaginative (defined in Appendix B) to parse the sample. Table 3 shows the break-down of levels of epistemic complexity by these categories.

Within the category of mechanical writing, more than half of the sample fell into the first level of epistemic complexity in the subcategories of short answer questions, fill-in-the-blank exercises, and symbolic representation. Short answer questions were the only type of mechanical writing at levels 4 and 5 and the percentage was quite low (3.4% and 1.1%). In contrast, the complexity level reflected in the informational writing was relatively high, especially in the subcategory of reading reflections and analyses. Students' writing showed at least some degree of explanation from 1.3% (in the subcategory of notes) to 47.4% (in the subcategory of reading reflections). Personal diary was the only subcategory identified in personal writing and this was indexed at the lower levels (one, two, and three).

Table 3. *Levels of Epistemic Complexity across Types of Writing (Percentages)*

	level 1	level 2	level 3	level 4	level 5	(nr of question items)
Mechanical						
short answer	54.7	28.4	12.4	3.4	1.1	1,202
fill-in-blank exercises	100	0	0	0	0	261
symbolic	61.1	5.6	33.3	0.0	0	22
table	20	50	30	0	0	13
Informational						
notes	58.5	22.7	17.5	0	1.3	140
lab reports	61.3	17.3	7.6	10.6	3.2	268
reading reflections	0	15.8	36.8	21.1	26.3	19
analyses	27.3	21.4	29.1	9.4	12.8	117
Personal						
diary	50	0	50	0	0	4

3.1 Epistemic Complexity by Language Background, Grade Level, and School Context

With regard to our second question (How does the level of epistemic complexity differ by adolescents' language background, grade level, and educational context?), we found some differences evident in the levels of epistemic complexity by students' language backgrounds, grade levels, and school contexts although only school context was found to be a statistically significant factor. It is important to note, as we will discuss later in the limitations section, that tests for statistical significance are weak on such a small sample.

Nonetheless, we found that although the mean level of epistemic complexity reflected in NESs' writing was higher than that in ELs' writing, there was no statistically significant difference in epistemic complexity among students of different language backgrounds. In addition, while there was no statistical significance in epistemic complexity by students' grade levels, the levels of epistemic complexity rise slightly by grade level from 1.49 at 6th grade to 2.17 at 12th grade. Finally, the mean level of epistemic complexity in the writing of students from California, Texas, and New York was 1.98, 1.24, and 1.93, respectively and the mean level of complexity in writing of students from the three states was statistically significant. A Scheffé test was performed to further identify where the statistical significance lay, and results showed that the difference existed between the level of epistemic complexity in the writing of students from California and Texas ($p = 0.05$; $SE = 0.28$). ANOVA tests generated the same results of the statistical significance with regard to students' language background, grade level, and school context, when we excluded the five students with fewer than two pieces of writing. These results can be seen in Table 4.

Table 4. Levels of Epistemic Complexity by Language Background, Grade Level, and School Context

Student type	M	SD	N	F	p-value
Language Background				1.38	0.25
NES	1.85	0.8	18		
EL	1.56	0.61	15		
Grade level				1.22	0.32
6	1.49	0.47	7		
8	1.63	0.84	10		
10	1.64	0.73	9		
12	2.17	0.73	7		
State				4.44	0.02*
CA	1.98	0.86	11		
TX	1.24	0.19	11		
NY	1.94	0.72	11		
Total	1.72	0.73	33		

* $p < 0.05$

3.2 The Nature of Epistemic Complexity in Different Types of Writing

Our third research question explored the nature of writing that exhibited lower and higher levels of epistemic complexity with particular interest in the kinds of writing in which adolescents moved beyond explanation (levels one, two, and three) to postulating causes, reasons and other relations or theories related to scientific phenomena (levels four and five). Here we begin by describing some examples of the types of mechanical writing we examined more closely (e.g., short answer and symbolic writing) and follow with examples of informational writing (e.g., reading reflections and labs) that illustrate contrasts in the types of writing associated with higher and lower levels of epistemic complexity.

Mechanical writing: Sometimes, but not always simple

As noted earlier, even though the students participating in the study produced a variety of writing in science classes, most of this work was mechanical in nature which did not require going beyond explanation. While much of the mechanical writing in our sample was indexed at the lowest level (level one) of epistemic complexity, and generally was indexed lower than informational writing, some types of mechanical writing exhibited higher levels of epistemic complexity and we were particularly interested in these. In some cases it appears that the higher level of epistemic complexity in the writing was as a result of the type of task and in other cases was related to the nature of the prompt.

Short answers and symbols: From lists to relationships

Of the mechanical writing in our sample, the majority was in the form of textbook, chapter review questions that are usually taken directly from the text or a pre-printed teacher's guide. These tasks require students to answer with one word or a short phrase. The pieces of mechanical writing in our sample generally did not exhibit high levels of epistemic complexity evidenced by the analysis of ideas in order to explain causal or other relationships or theorizing about these relationships. An example of such a textbook chapter review task found in the samples produced from a sixth grade classroom in Texas asked students to define non-renewable resources. An English learner in this class responded with the following phrase: "not replaced as it is being used. Ex. fossil fuels, metal (recycle), uranium)". This exemplifies epistemic complexity of level one.

In contrast, some mechanical pieces such as short answer and symbolic writing qualified as levels two and three on our scale. In one such short answer example, produced in an Honors Chemistry class and in response to the prompt: "concepts to learn for this experiment." a 10th grade, native English speaker from California wrote, "Some solutions conduct electricity, only ionic compounds conduct electricity because of the presence of ions." The epistemic complexity here is level two showing evidence of making a causal explanation between scientific concepts.

While 61.1% of writing coded as symbolic was indexed at level one in terms of epistemic complexity, 33.3% of these kinds of writing were indexed at level three. These level three symbolic writing samples demonstrated well-organized descriptive information. For example, a sixth grade EL from Texas produced an elaborate diagram of the geological dimensions and relationships between igneous and sedimentary rock and how geological forces, such as volcanic activity, produce molten material (Figure 2). This piece was indexed at level three as the student did not only list terms, but also connected these terms by providing details as to their relationships.

In another example, a native English speaking senior from California, drew directional lines to articulate the relationship between phase changes as liquid moves through the three states of matter. In this example, like the previous one, single words were used to capture elements of the phase changes between states of matter.

Thus, not all mechanical writing in our sample was simple; in some cases short answer and symbolic writing was related to higher complexity requiring the reorganization of information. However, this writing fell short of providing evidence of claims, counterclaims, and the provision of evidence to support claims.

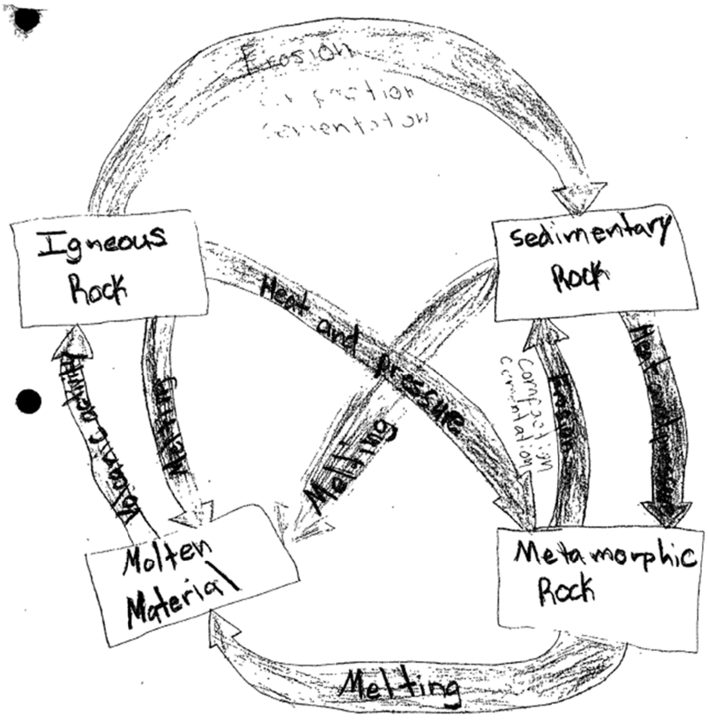
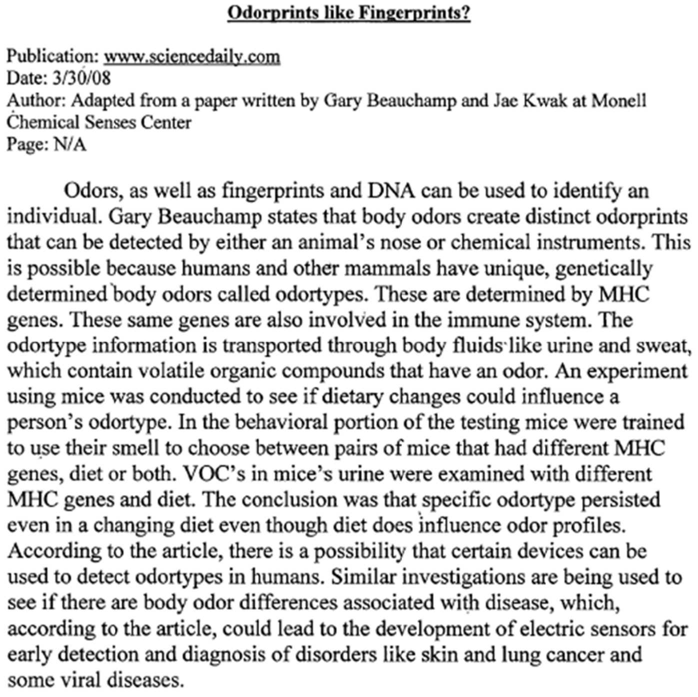


Figure 2. *Symbolic writing.*

Informational writing: Sometimes, but not always, complex

The informational writing in our sample tended to be of higher epistemic complexity than mechanical writing overall. Reading reflections, for example, more than any other type of writing, were indexed at level five. Yet, some reading reflections were associated with very low levels of epistemic complexity. Likewise, some lab reports were associated with lower levels of complexity and others much higher. What is it, precisely, about the nature of this writing that related to higher or lower levels of epistemic complexity? In this section, we begin with descriptions of reading reflections, followed by lab reports, to identify the distinguishing characteristics of informational writing tasks indexed at higher levels of epistemic complexity and those that were not.

Reading reflections. Reading reflection-typewriting prompts can take many forms such as summaries and reports. The most important characteristic we noted in this regard is that, unlike mechanical writing prompts which restrict student responses, (there is a correct answer the teacher is looking for), reading reflection questions were often open-ended and provided the student an opportunity to think about, reflect upon, and articulate their questions and emerging understandings. In addition, they sometimes required students to engage in analysis, synthesis, and summary. For example, Randy, one of the 10th grade students in California, enrolled in an Honors level Chemistry course, wrote analyses and summaries of topical writing appearing in science or popular science journals (Remark: All student names are pseudonyms). In these Randy synthesized, analyzed, and reflected on the content. For example, in one writing piece, entitled "Oderprints like fingerprints?" Randy not only summarized the key findings of the article, he also explained the scientific underpinnings justifying the use of odorprinting to identify individuals (see Figure 3).



Odorprints like Fingerprints?

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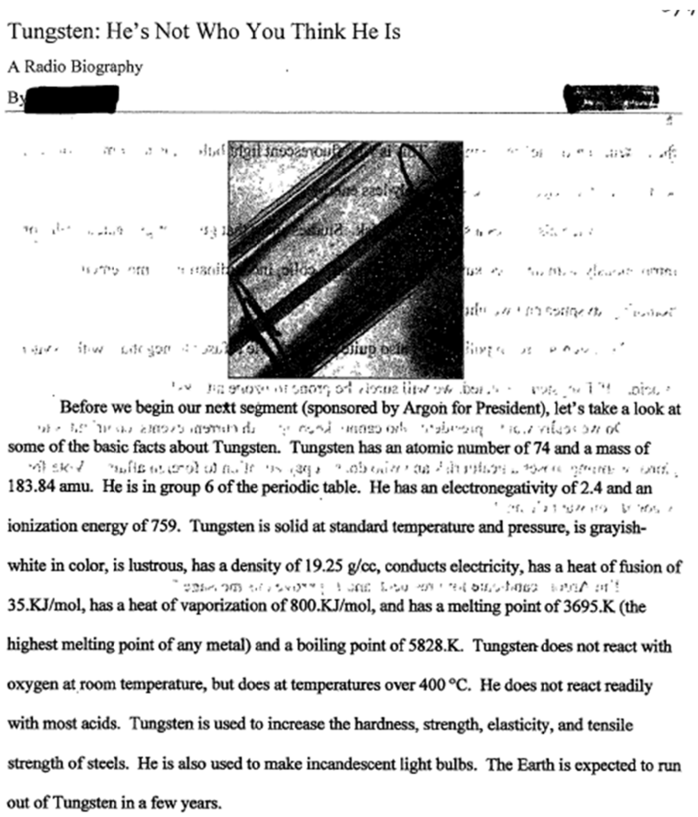
Date: 3/30/08
Author: Adapted from a paper written by Gary Beauchamp and Jae Kwak at Monell Chemical Senses Center
Page: N/A

Odors, as well as fingerprints and DNA can be used to identify an individual. Gary Beauchamp states that body odors create distinct odorprints that can be detected by either an animal's nose or chemical instruments. This is possible because humans and other mammals have unique, genetically determined body odors called odortypes. These are determined by MHC genes. These same genes are also involved in the immune system. The odortype information is transported through body fluids like urine and sweat, which contain volatile organic compounds that have an odor. An experiment using mice was conducted to see if dietary changes could influence a person's odortype. In the behavioral portion of the testing mice were trained to use their smell to choose between pairs of mice that had different MHC genes, diet or both. VOC's in mice's urine were examined with different MHC genes and diet. The conclusion was that specific odortype persisted even in a changing diet even though diet does influence odor profiles. According to the article, there is a possibility that certain devices can be used to detect odortypes in humans. Similar investigations are being used to see if there are body odor differences associated with disease, which, according to the article, could lead to the development of electric sensors for early detection and diagnosis of disorders like skin and lung cancer and some viral diseases.

Figure 3. *Summary.*

He writes: "This is possible because humans and other mammals have unique, genetically determined body odors called odortypes." Then, he applies his understanding as he elaborates on the potential application of such scientific developments. This piece was categorized at level five, not merely because it was more than a few sentences, but because Randy's explanation is explicit and postulates causes and reasons, and his reflection indicates application of his understanding as he notes the possibility of odorprinting "being used to detect skin diseases."



Tungsten: He's Not Who You Think He Is

A Radio Biography

By [redacted] [redacted]

Before we begin our next segment (sponsored by Argon for President), let's take a look at some of the basic facts about Tungsten. Tungsten has an atomic number of 74 and a mass of 183.84 amu. He is in group 6 of the periodic table. He has an electronegativity of 2.4 and an ionization energy of 759. Tungsten is solid at standard temperature and pressure, is grayish-white in color, is lustrous, has a density of 19.25 g/cc, conducts electricity, has a heat of fusion of 35.KJ/mol, has a heat of vaporization of 800.KJ/mol, and has a melting point of 3695.K (the highest melting point of any metal) and a boiling point of 5828.K. Tungsten does not react with oxygen at room temperature, but does at temperatures over 400 °C. He does not react readily with most acids. Tungsten is used to increase the hardness, strength, elasticity, and tensile strength of steels. He is also used to make incandescent light bulbs. The Earth is expected to run out of Tungsten in a few years.

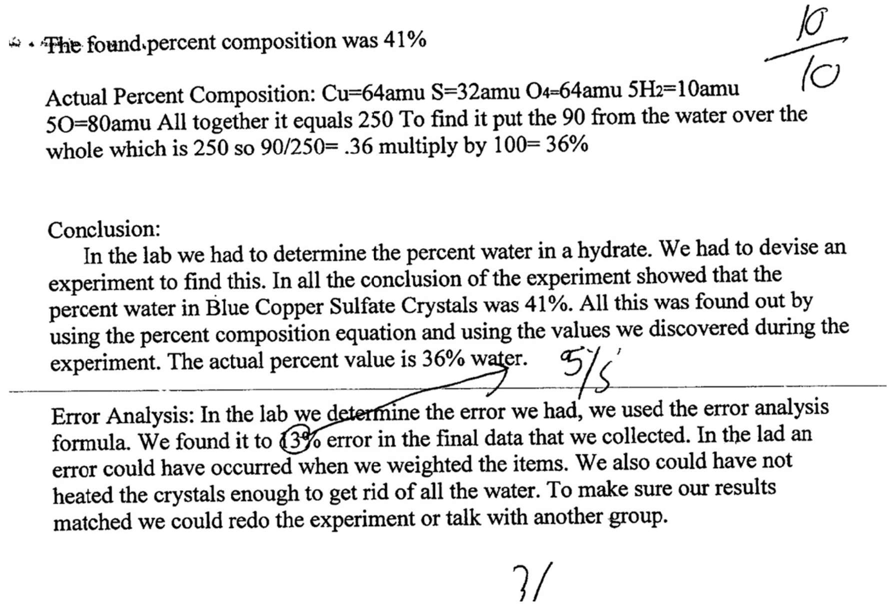
Figure 4. Report.

While it may be easy to suppose that Randy, in the preceding example, is a high-achieving student in an Honors Chemistry class, that very high levels of epistemic complexity may only be associated with work in such classes and by students who qualify to be in such classes, this was not always the case. We also had examples of ELs in regular (non-Honors) classes who produced writing of equal complexity. For instance, Shane, a tenth grade English learner from New York in a non-Honors science class also produced writing indexed at level five. Shane was required to research a chemical element and write a "Radio Biography" (a narrative script intended to be read aloud to a non-scientific community). After citing several sources for his script, Shane frames his script as an endorsement for the element tungsten as a presidential candidate. He argues his stances on key issues such as "Tungsten's foreign policies are also quite dreadful. He refuses to negotiate with oxygen or acids. If Tungsten is elected, we will surely be prone to ozone attacks". An excerpt of this piece is shown in Figure 4. Shane's one and a half page report synthesizes the key facts, but more importantly, his explanation of what Tungsten can and won't do, framed as a political candidate, shows deep understanding of chemical relationships and causality, even going so far as predicting what might become of this chemical element if placed in a political arena.

These two examples of reading reflections required students to analyze different texts, synthesize information, and articulate their explanations with different audiences and purposes in mind. The demands of these reading reflections are not simply "what did you learn?"; These tasks, synthesizing popular science writing and reflecting on the implications, and recasting a research report into a radio biography invited students to fulfill many of the demands of the Common Core State Standards and the Next Generation Science Standards described at the beginning of this article.

Lab reports

Like reading response, lab reports also varied in the levels of epistemic complexity. The lab report, a hallmark of secondary science classwork, typically engages students in articulating phases of the scientific method (e.g., identifying problems, hypothesizing, articulating procedures, and making conclusions based on evidence). In one case, Dave, a low achieving, native English speaking student from New York, produced a response to a lab assignment on water in a typed response. In this assignment and working with another student, Dave summarized the conclusions, but also added an "error analysis" section making inferences about why he and his lab partner may have found different results in their data compared to other students (Figure 5). Dave and his partner write: "In the lad [sic] an error could have occurred when we weighted the items. We also could have not heated the crystals enough to get rid of all the water." This piece of writing was indexed at level three, relatively high, which would not have been the case if the writing prompt itself did not call for identifying flaws in lab procedures invoking what was discussed earlier as movement toward an evaluativist stance where scientific knowledge is understood and explained as tentative and contingent.Lab reports, though, did not always correlate with higher levels of epistemic complexity. The majority of lab report writing in our sample was tightly scripted, leaving little room for students to explain the phenomenon they were observing. Note that 61.3% of all lab writing from our sample was indexed at level one and 17.3% was categorized at level two. As evidence of this pattern, Shane, one of the ELs from New York, engaged in a "Redox Reactions" lab and was prompted to burn copper over a flame and describe the reaction that occurred. Shane writes "the copper quickly burned, producing a yellow flame." The entirety of the lab report asks students for short descriptions of observations such as this one, but only asks students to construct a chemical equation to represent the observed reaction, resulting in symbolic writing. Nowhere throughout the lab is Shane asked to draw conclusions, recognize patterns, or make inferences about his observation of natural phenomena and he does not do so. The chemical equations demonstrate to the teacher grading the assignment that Shane can construct balanced chemical equations, likely meeting a major learning objective



The found percent composition was 41%

10/10

Actual Percent Composition: Cu=64amu S=32amu O_4=64amu $5H_2$=10amu 5O=80amu All together it equals 250 To find it put the 90 from the water over the whole which is 250 so 90/250= .36 multiply by 100= 36%

Conclusion:

In the lab we had to determine the percent water in a hydrate. We had to devise an experiment to find this. In all the conclusion of the experiment showed that the percent water in Blue Copper Sulfate Crystals was 41%. All this was found out by using the percent composition equation and using the values we discovered during the experiment. The actual percent value is 36% water.

5/5

Error Analysis: In the lab we determine the error we had, we used the error analysis formula. We found it to 13% error in the final data that we collected. In the lad an error could have occurred when we weighted the items. We also could have not heated the crystals enough to get rid of all the water. To make sure our results matched we could redo the experiment or talk with another group.

7/

Figure 5. Lab.

of this task, but Shane does not show evidence of making sense of his observations (i.e., reasoning) in light of scientific theories or concepts he has previously learned.

In sum, these examples were selected for their illustrative nature as they capture the general pattern observed in student writing samples of a relationship between epistemic complexity and both the task structure and qualities of writing prompts (whether restrictive or not) in those tasks.

4. Limitations

As part of a complex larger study, the current study faced several limitations that are important for readers to note in considering the findings and conclusions. First, the sample was purposive and not intended to be representative of science writing among adolescents in U.S. secondary schools. Generalizability was not a goal, but rather, insight into the nature of science writing in what might be considered "better-case scenario" schools (i.e., those with histories of exemplary writing performance). In addition, one of the data points not of concern in the larger study was the writing prompt or task description that foregrounded the students' writing. In some cases, the students' writing followed these task descriptors and so this information was available to us within the sample; however, this was oftentimes not the case. In any event, we could not systematically analyze the tasks and prompts that would have provided interesting insight into the relationships of the nature of tasks and prompts and the qualities of the writing students produced in terms of epistemic complexity. We also did not have access to what materials students may have used in preparation for their writing and these materials may have influenced what they wrote such as in the case of paraphrasing the language used in a source text. Therefore, whether a student actually was engaging in a particular kind of reasoning or mimicking the reasoning of another writer in their written work is unclear. Finally, the scale of epistemic complexity we utilized is only one option that inevitably takes some things into account and not others. So, for instance, although the example of the metaphor of Tungsten as a political candidate was scored fairly high on the scale of epistemic complexity we used, it might be viewed as a simple description using other measures.

5. Discussion

We found that the types of writing secondary students in our study produced were generally not of high levels of epistemic complexity. This is particularly true of English learners, students at the lower grades (6th and 8th), and students in some school contexts where there appears to be little emphasis on more complex writing in science classrooms.

Although the total amount of writing English learners produced was more than that of native English speakers, EL writing was largely mechanical and fell into levels one and two while native English speaking students produced a higher percentage of informational writing and overall their writing was more complex although these differences were not statistically significant. Nevertheless, this finding suggests that language background related to differences in the complexity of adolescents' science writing to some extent. This finding raises questions as to whether the root of this contrast is in different opportunities for writing, English learners' stage of language development, or some combination of a variety of these and other factors.

Like the differences in epistemic complexity by language background, differences by grade level were also not significant. However, the pattern that we noted showed an increase in complexity evident in the writing of upper-classmen (i.e.,12th graders) in comparison with students in lower grades. Indeed, one would expect that epistemic complexity would be higher as students progressed in their schooling and this was the case in our sample. Whether this was due to teachers' expectations, students' in-school and out-of-school experiences, or some variety of other factors is unclear from our data.

The findings regarding differences by school contexts (e.g., students from New York produced the highest percentage of informational writing and writing of higher epistemic complexity in science overall than those in other states) may relate to the fact that New York was the only state which had open-response questions on the high stakes exit exam in science. This finding raises further questions as to the influence of high stakes exams on teachers' expectations for writing and instructional emphases in secondary science classrooms.

Our analyses revealed that mechanical writing was associated with lower levels of epistemic complexity in comparison to informational writing. Yet, while overall, mechanical writing was associated with lower levels of epistemic complexity, it was not exclusive of more complex explanations of relationships or theorizing about scientific concepts. In fact, some of the student writing categorized as mechanical did require some more complex articulations; albeit the examples of these were limited. Likewise, we found that not all informational writing was complex; both reading reflections and lab reports were associated with varying levels of complexity and in some cases this appeared to relate to the task structure and in others the quality of the prompt. In this regard, prompts that were characterized by invitations for students to manipulate and make sense of content demonstrated higher levels of epistemic complexity.

Although the results of this study are not generalizable to the writing experiences of all secondary adolescents in the United States, they highlight the nature of writing in terms of epistemic complexity among students in a set of schools identified for exemplary writing performance (potentially better-case scenario contexts) that nonetheless produced writing at fairly low levels of epistemic complexity. The finding that the sample showed evidence of a paucity of epistemically-complex science writing overall, and a preponderance of writing at lower levels of epistemic complexity particularly in the samples from English learners and middle-level students and those from contexts where writing in science is not as strongly emphasized in high stakes exams hold implications for future research and practice.

6. Conclusion

From a sociocultural perspective, our study highlights the myriad ways adolescents were engaged in making sense of scientific phenomena in their writing, yet also revealed that of all of the writing they produced, very little of it involved wrestling with scientific problems as more expert scientists do. This finding draws attention to the concerns outlined at the beginning of this article with regard to how well adolescents are developing 21st Century skills and dispositions toward writing in the academic disciplines and how well they are being prepared to engage in writing that aligns with more rigorous standards such as the Common Core State Standards and Next Generation Science Standards (Green, & Dixon, 1993; Jimenez-Aleixandre, Rodriguez, & Duschl, 2000; Lemke, 1990; Rijlaarsdam, et al., 2006).

Although the Common Core State Standards and Next Generation Science Standards place an emphasis on developing students' capacities to make arguments and understand the nature of evidence in the scientific domains, our study reveals that many of the students in even historically better schools in terms of writing instruction may not achieve these standards in their writing. The reasons for this are likely multiple including, as other researchers have found, (Owen, 2001; Tsai, 2002), that oftentimes teachers' beliefs about the nature of science as it might be revealed in discourse – including writing - is reproduced rather than constructed. However, as standards and standardized testing requirements shift to a stronger emphasis on more advanced disciplinary discourse, secondary science teachers may change their beliefs about the value of writing and may be offered guidance and support in developing their understandings of the epistemological foundations of scientific knowledge and how these are expressed in different kinds of writing.

The building blocks may already exist for this transformation. Our analyses revealed that even some forms of mechanical writing such as short answers, that are already part of many science teachers' repertoires, may facilitate adolescents' development in argumentation and explanation if they are well-prompted and scaffolded. As Langer and Applebee noted in their study decades ago, "writing tasks differ in the breadth of information drawn upon and the depth of processing of that information that they invoke" (1987, p. 131). So, while we noted that reading response and lab report tasks were associated with higher levels of complexity overall, we also identified those that were not. We also found writing samples that qualified as mechanical (e.g., short answer and symbolic) in which students engaged in articulating detailed understandings going well beyond recall of facts and others that were of higher epistemic complexity. In the end, the nature of the task and prompt matter a great deal as we have highlighted in our illustrative examples, and teachers can learn how to use writing to achieve different aims if they also understand how to construct the tasks and prompts carefully.

Our earlier discussion of the epistemology of science and its relationship to epistemic complexity in writing may shed some insight into questions teachers may have as to why certain writing tasks and prompts might be proposed in particular ways. Drawing on Kuhn & Crowell's (2011) work in the teaching of dialogic argumentation as a means for students to internalize more mature understandings of the epistemology of science, we glean some guidance as to how teachers might frame writing tasks as a dialogic endeavor. Like the example "odorprints" described earlier, a science writing pedagogy that engaged adolescents in dialogic argumentation including explaining, justifying, and identifying causal relationships with regard to some scientific phenomenon, followed by a task prompting them to express these ideas and their implications in relationship to existing scientific knowledge and theories, might be fruitful. Such an instructional approach may help students begin to grasp the epistemological underpinnings of science content while also developing their disciplinary writing competence. Secondary school teachers of science in an era of the CCSS and NGSS and guided by an emphasis on the development of 21st Century dispositions and skills might consider the kinds of writing tasks and prompts associated with higher levels of epistemic complexity such as these as essential components of adolescents' preparation for the workplace or post-secondary study. As we noted in our review of literature, if one of the purposes of writing in science is to "foster deep thinking about science" (Keys, 1998), then secondary teachers need to think carefully about the intended outcomes of assigning tasks that constrain adolescents to solely recall of facts.

This study, informed and complemented by others (Rijlaarsdam, Couzijn, Janssen, Braaksma, & Kieft, 2006; Rivard, 1994; Tsai, 2002; Wellington & Osborne, 2001; Wilcox & Jeffery, 2014), contributes to the research literature an account of the kinds of writing tasks a variety of students from different secondary school contexts produce. It also offers a potentially useful approach to the analysis of science writing, the results of which might provide some guidance to secondary science teachers in contemplating the qualities of writing tasks as they relate to intended outcomes. If, as we have argued, one of the values of writing in science is to prompt deep understanding of content – including the epistemological underpinnings of scientific knowledge, and ultimately build dispositions and skills to engage in and with the scientific community as young adults, further investigation beyond this study is needed. Studies exploring the relationships between the qualities of tasks and prompts and levels of epistemic complexity in a broader sample of adolescents' writing may help build a stronger and deeper conceptualization of science writing development and its pedagogical applications.

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Appendix A. School Demographics

State	School	Size	Grade Span	% F/RL	% ELL	% African-American	% Hispanic	% White	% Asian or Native Hawaiian/ Other Pacific Islander	% American Indian/Alaska Native	District-wide total per pupil $ expenditure
CA	Montebello	1,664	5 to 8	83	28	0.2	96.5	2	1.1	0.1	$8,764
CA	John Adams	977	6 to 8	44	16	10.2	50.2	33.1	4.4	0.1	$10,130
CA	King Drew	1,680	9 to 12	66	3	59.5	37.8	0.3	0.9	0.2	$10,590
NY	Albert Leonard	1,195	6 to 8	25	1	29	22	45	5	0	19,356
NY	Port Chester	794	6 to 8	43	12	9	72	18	1	0	17,046
NY	Batavia	763	9 to 12	34	0	8	2	87	2	1	$16,928
NY	New Paltz	803	9 to 12	14	0	7	6	84	3	0	$18,016
TX	Grisham	657	6 to 8	19	4	6.7	17.7	59.4	16.2	0	$7,191
TX	Spring Branch	763	6 to 8	20	3	2.2	25	70.5	2.2	0	$6,926
TX	McCallum	1,718	9 to 12	35	5	21.6	29.8	46.3	2	0.3	$8,141
TX	Round Rock	2,648	9 to 12	24	5	10.7	26.6	57.2	5.1	0.4	$7,191

Appendix B. Categories of Writing

The categories of function refer to the way the language is used in a piece of writing. Below are four main categories of function and a brief description of each based on the work of Applebee (1981).

Writing without Composing (or Mechanical Uses of Writing: Tasks which require written responses but that do not require the writer to organize text segments of more than a paragraph length. Subcategories include: Multiple-choice exercises, fill-in-the-blank exercises, short answer exercises, transcription from written material (copying) or oral material (dictation), translation, symbolic expression (diagrams, graphs).

Informational Writing*: Writing which focuses on the sharing of information or opinions with others*. This includes the wide variety of forms of expository writing, ranging from simple reports about specific events to highly abstract, theoretical arguments. It also includes writing where the attempt to persuade overrides all other purposes (as in advertisements or propaganda), and regulative writing (e.g., laws or school rules). Subcategories include: Note taking, record, report, summary, analysis, theory, persuasive essay.

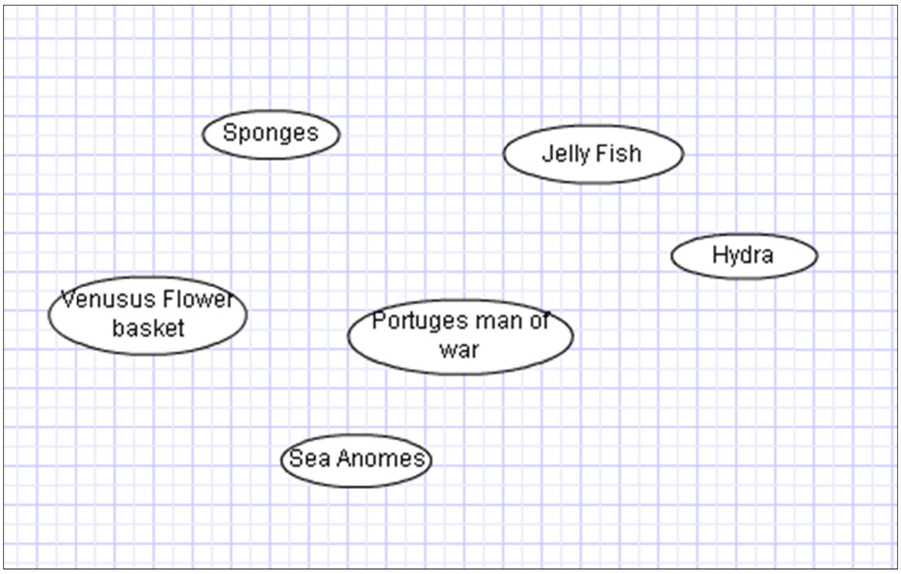
Personal Writing: Writing that is embedded within a context of shared, familiar concerns. The audience for such writing is usually the self or a very close friend; the function is to explore new ideas and experiences simply to sort them out, rather than to make a specific point. Gossip in spoken language illustrates the general category; in school writing, this use occurs mostly in journals or "learning logs" where new ideas are explored for the writer's own benefit. Subcategories include: Journal, diary, notes, personal letters.

Imaginative Writing: Writing within any of the various literary genres. Subcategories include: Stories, poems, play scripts.

Appendix C. Coding Scheme for Epistemic Complexity

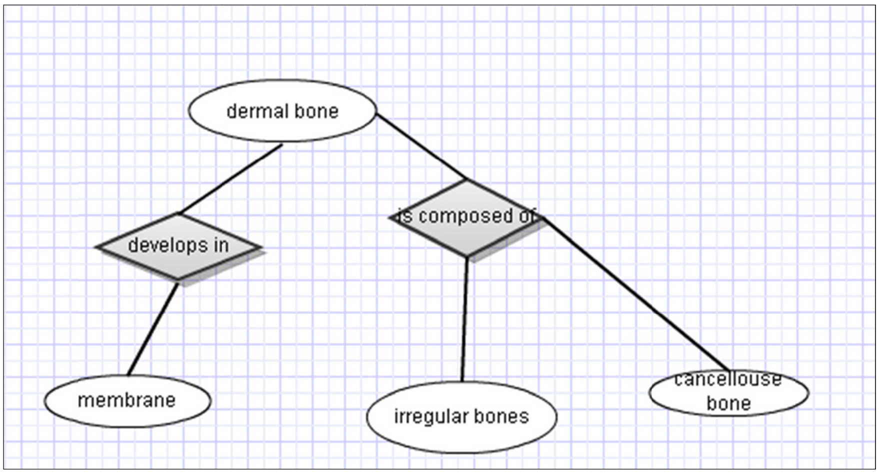
Level 1: Separated pieces of facts. A rating of 1 was assigned to students' writing statement if it was transformed to a concept map with one entity or a group of entities without any relationship. Entities might have a descriptive or multiple descriptives, but no relationship existed between different entities. For example:

Some related animals are, Sponges, Venuses Flower basket, Portuges[sic] man of war, Sea Anomes [sic], Jelly Fish and Hydra.



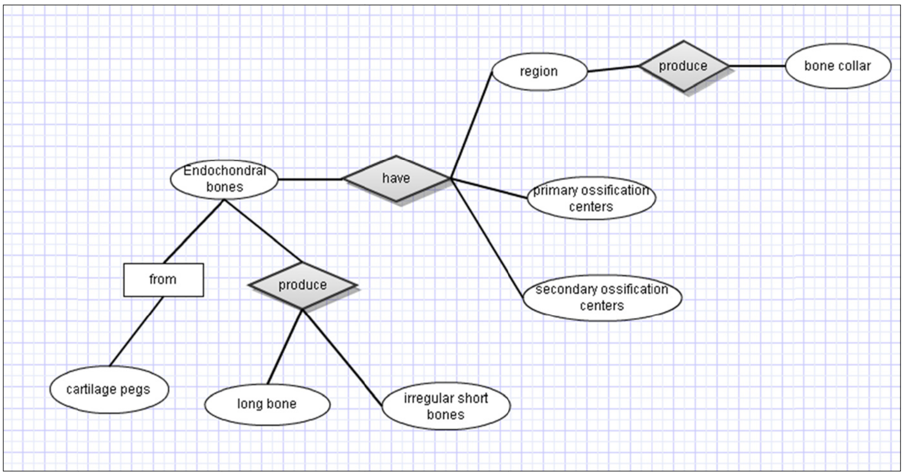
Level 2: Partially-organized Facts. A rating of 2 was given to ideas that represented loosely connected pieces of factual information. Visually, two or multiple entities had only one layer of relationship within or among each other. For example:

Dermal bones form in subcutaneous membranes. They're mostly composed of cancellouse bone and parts of irregular bones.



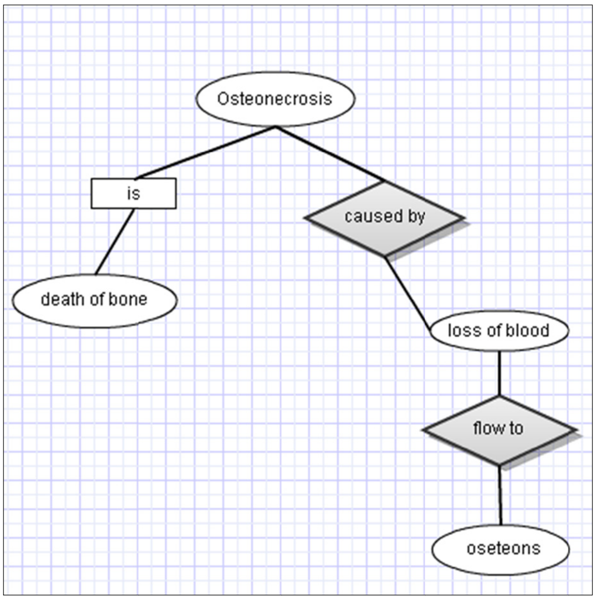
Level 3: Well-organized Facts. A rating of 3 was assigned to writing statements in which factual information was introduced in a well-organized way. It was represented by two or multiple entities with multiple layers of a relationship within or among each other on the concept maps.

Endochondral bones form from cartilage pegs in the embryo. They usually produce long bones, and parts or irregular and short bones. Endochondral bones have primary and secondary ossification centers, and a region that produces the bone collar.



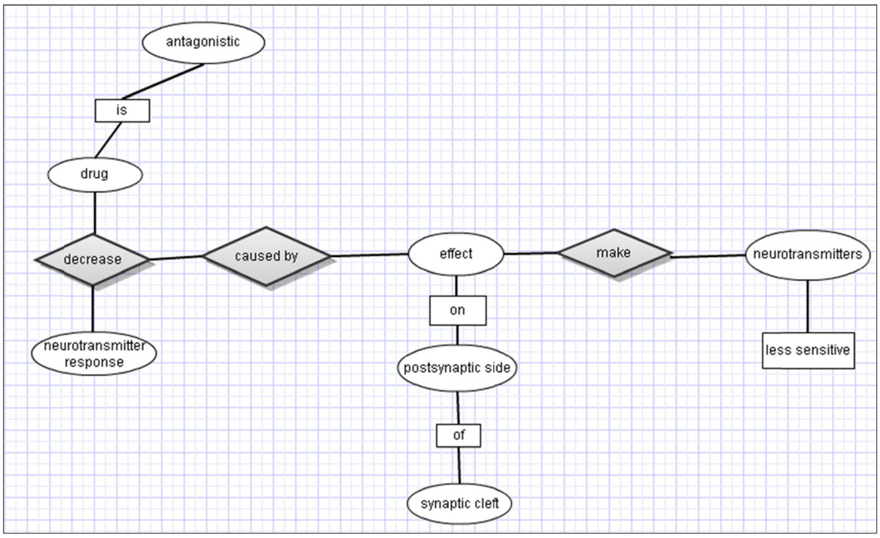
Level 4: Partial explanation. A rating of 4 was assigned to ideas that represented some characteristics of an explanation but the content of the explanation was limited or only partially articulated. It was transformed to concept maps as entities with a cause/effect relationship, but the logic sequence was incomplete, meaning some essential entities or relationships were missed. For example:

Osteonecrosis is death of bone caused by loss of blood flow to the oseteons.



Level 5: Well-organized explanation. A rating of 5 was given to writing statements for which a relatively well elaborated explanation was provided. On the concept maps, two or multiple entities had a cause/effect relationship with a complete logic sequence containing all essential nodes. For example:

A drug described as antagonistic would decrease the normal neurotransmitter response. The mechanism of such a drug if it were to exert it effects on the postsynaptic side of the synaptic cleft would result in less sensitivity to neurotransmitters.



Appendix D. Levels of Epistemic Complexity by Language Background, Grade Level, and School Context

Student type	n	M(SD)	F-value	p
Language Background			1.29	0.27
NES	18	1.85 (0.80)		
EL	15	1.56 (0.61)		
Grade level			1.22	0.32
6	7	1.49 (0.47)		
8	10	1.64 (0.83)		
10	9	1.64 (0.73)		
12	7	2.17 (0.73)		
State			4.44	0.02*
CA	11	1.98 (0.86)		
TX	11	1.24 (0.19)		
NY	11	1.94 (0.72)		
Total	33	1.72 (0.73)		

Note. * $p < 0.05$