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How Students Argue Scientific Claims: A Rhetorical-Semantic Analysis

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This paper investigates ways students engage in scientific reasoning practices through the formulation of written argument. Through textual analysis of university students' scientific writing we examined how general theoretical claims are tied to specific data in constructing evidence. The student writers attended a writing-intensive university oceanography course that required them to write a technical paper drawing from multiple interactive geological data sets concerning plate tectonics. Two papers, chosen as exemplary by the course instructor, were analysed in three ways: First, genre analysis was applied to identify the rhetorical moves used by the authors to complete the academic task. Second, a previously developed model of epistemic generality was used to uncover the relationships of theoretical assertions and empirical data. Third, an analysis of lexical cohesion mapped the recurrence and relationships of topics throughout the student papers. These analyses identified ways that the students engaged with the genre (as defined within the activity system of the course): the successful student authors were shown to adjust the epistemic level of their claims to accomplish different rhetorical goals, build theoretical arguments upon site specific data, method, introduce key concepts that served as anchors for subsequent conceptual development, and tie multiple strands of empirical data to central constructs through aggregating sentences. Educational applications are discussed.

Several recent studies of science education have provided evidence for the importance of writing in students coming to understand and use scientific concepts (Rivard and Straw 2000; Prain and Hand 1999; Keys 1999, 2000; Keys *et al.* 1999), as well as learning to participate in science as a learning community (Chinn and Hilgers 2000). These findings are consistent with much of the theory and research developed over the last three decades in writing across the curriculum, which has focused both on writing to learn (Britton *et al.* 1975; Emig 1977; Fulwiler and Young 1986), and writing communities in the classroom (Walvoord and McCarthy 1990; Walvoord 1997; Herrington 1985; McCarthy 1987; MacDonald and Cooper 1992).

These educational studies have been developing in tandem with a recognition that writing and argument play important roles in scientists' and technologists' thinking and forming knowledge communities (Atkinson 1999; Bazerman 1988; Harris 1997). The forms of expression, invention, and knowledge are responsive to the particular argumentative fields of the professions and disciplines. The epistemic activity of researchers is shaped by rhetorical concerns of who is to be convinced of what, how others respond to novel work, what the organization of their communicative activity is, and what the goals of community cooperation are (Bazerman 1981, 1988; Berkenkotter and Huckin 1995; Bijker *et al.* 1987; Blakeslee 2001; Gross 1990; Knorr-Cetina 1999; Latour 1987; Myers 1989; Pinch 1986; Swales 1998; van Nostrand 1997; Winsor 1996). The representation and role of evidence in relation to generalizations and claims has been a particularly crucial matter in the development of scientific argument (Bazerman 1988; Chandler *et al.* 1991; Fleck 1979; Lynch and Woolgar 1990; Poovey 1998).

In this paper we consider how research in science education can be brought together with research in science studies (i.e. the philosophy, sociology, anthropology, and rhetoric of science) and in academic and scientific writing to consider evidence formation in student writing. Theoretically, we draw from studies of scientific practices, argumentation analysis, applied linguistics, and rhetoric to argue for the many ways writing can be used to provide opportunities for students to engage with scientific knowledge and practices from a disciplinary point of view. We then turn to the empirical study of two student papers. This analysis considered the students' rhetorical moves, epistemic levels of claims, and lexical cohesions as dimensions of persuasive uses of evidence. Finally, we raise some relevant discussion points and propose educational implications.

SCIENCE, RHETORIC, AND EDUCATION

Rhetorical studies of science view knowledge as actively constructed by scientists working individually or collectively on problems and being held accountable to public standards. This perspective highlights scientists' need to refine reasoning, limit theoretical claims, marshal evidence, and understand the strengths and limits of their evidence and arguments so as to make credible and creditable knowledge claims within their knowledgeable and critical communities of peers (Latour 1987; Myers 1990; Pinch 1986). Thus, studies of scientific argument, and writing in particular, evince the situated, local aspects of persuasion as well as the constraints posed by the norms of the relevant communities (Gieryn 1999). These issues become salient when considering student engagement in the sociocognitive practices of writing in educational settings.

Work in the specialized argumentative practices of the various disciplines suggest that students not only need to write in order to master the concepts and work of a field, but more particularly to develop competencies in the specific argumentative practices of their fields (Kelly *et al.* 2000). In addition to the genre-specific writing competencies, with associated argumentative patterns, students must begin to gain a feel for the argumentative forums and dynamics of their fields. They must learn the kinds of claims people make; how they advance them; what literatures people rely on and how these literatures are invoked within arguments; what kind of evidence is needed to warrant arguments and how that evidence can be appropriately developed, analysed, and interpreted given community standards; what kinds of concepts are appropriately evoked; and what kind of stance authors can appropriately take as contributors to their fields. As students engage in serious writing practices, they move beyond a simple formal approach to science to active work with scientific evidence, knowledge, and concepts, thereby learning social disciplinary standards and practices.

In becoming disciplined participants in the scientific endeavour students not only develop their individual communicative skills, they enter into community practice of empirical investigation and application of communally developed knowledge to problems of our common life. In this way knowledge formation can be perceived as more than an individual function; rather it is part of a communal engagement with the material world (Goodwin 1995). Within this communal engagement with the material world, the role of evidence has been centrally important. The philosophic and rhetorical concern for the relations of general ideas to concrete details of the observed world go back at least to Plato (Phaedrus, for example) and Aristotle (see his consideration of non-artistic proofs in *On Rhetoric*, 1991), but the emergence of early science reversed the scholastic stance toward specifics. Whereas earlier forms of knowledge massively privileged recurrent experiences and tended to neglect the anomalous, one-of-a-kind detail, modern experimental science gave special status to the unusual detail as a challenge for accepted ideas. During the Scientific Revolution, detailed individual accounts of precisely documented particulars were tied to general theoretical claims (Dear 1991). Thus Francis Bacon's House of Salomon described in the New Atlantis (Bacon 1974) contains collectors of experiments and doers of new experiments as well as synthesizers and interpreters. Similarly, Priestley (1767) saw the necessity of collecting all the particulars of experience in the historical record and tying these to general claims through explicit argumentative reasoning. Currently, scientific fields generally endorse and enforce high levels of accountability between detailed findings and general idea claims through review and argumentation processes (Bazerman 1988; Myers 1990).

Rhetorical analyses of writing in scientific professions have tended to go in two directions. First, analyses have examined the historically emergent forms of argument deployed in professional practice—the genres and the activity systems they are part of (Bazerman 1988, 1994, 1997; Prior 1998; Berkenkotter and Huckin 1995; Coe 2001; Freedman and Medway 1994; Swales 1990; van Nostrand 1997). Such studies help orient writers and students to the general argumentative terrain they are entering, the tools and constraints that form their writing workspace, and the tasks, expectations, and audiences they need to address. Second, other related analyses have looked at the rhetorical specifics and strategies of individual cases of argument (Bazerman 1984, 1993; Pera and Shea 1991; Montgomery 1996). Sometimes such specific case studies have identified widespread rhetorical techniques used in scientific argument (Prelli 1989; Locke 1992; Pera 1994; Fahnestock 1999). These case specific studies orient writers and students to the local struggle they must engage in with their writing and the strategies that they might use.

But what is missing from both for a truly effective pedagogy is a way to bring them together—to consider how local rhetorical argument is carried out within the ordered terrain of differentiated genres and activity systems (Bazerman 1999). This paper considers local linguistic, argumentative choices within the frame of a genre's organization and the expectations invoked within the activity system—as here encapsulated in a particular school assignment that foregrounds the crucial issue of the use of particular evidence in relation to general claims.

WRITTEN ARGUMENT IN SCIENCE EDUCATION

Argumentation has recently come to be seen as relevant to science education (e.g. Kelly *et al.* 1998; Kuhn 1993; Richmond and Striley 1996). Driver *et al.* (2000) have provided a rationale for a greater emphasis on argument in science pedagogy and noted that current practices in science teaching offer students few opportunities to engage with scientific evidence, models, and socioscientific issues. They based their position on practice-based research concerning uses of argument in science and on normative goals for the development of students' understanding of science concepts, investigative strategies, and epistemology. In an empirical study, Jimenez-Aleixandre *et al.* (2000) applied argumentation analysis to student conversations about genetics to distinguish engagement in science from narrower engagement in the specified school task. This study considered both argumentative operations (following Toulmin's layout of arguments) and epistemic operations (e.g. induction, deduction, causality, plausibility, among others) within student discourse to display student engagement with scientific knowledge.

While most studies of student argumentation have focused on spoken discourse, written argument poses unique possibilities and challenges for science education. The use of argumentative writing to develop student scientific knowledge holds the promise of socializing students into legitimized, hence powerful, social practices. Writing provides a potentially useful strategy to engage students in the social and cognitive practices of evidence formation. Writing tasks can be constructed using the disciplinary resources of data and investigative tools to socialize students to disciplinary knowledge, norms, and practices. In the case to be examined below, students use real earth data sets as evidence in identifying geological structures, explaining dynamic processes of geologic activity at specific sites, and elaborating geologic theory. Thus, written argument can be used pedagogically to develop realistic learning tasks for students as they learn about the disciplinary practices of their chosen fields. Written argument can also be used to assess students' engagement with scientific knowledge, norms, and practices by identifying ways students are able to argue within the rhetorical space of various academic tasks, within the constraints posed by available relevant knowledge and information, and within the norms of their respective disciplinary fields as posed by the organization of educational activity.

The effective use of scientific argumentation in classrooms, however, presents several challenges. Foremost, written argument requires many general as well as site-specific language skills. Written argument requires students to draw on diverse knowledge and practices, including conceptual knowledge specific to the scientific discipline, rhetorical knowledge specific to the genre conventions of the discipline and writing task, and linguistic knowledge of lexicon and grammar (Halliday and Martin 1993). Furthermore, scientific practices are not universal (e.g. Knorr-Cetina 1999), but specific to units of various levels, for example disciplines, research areas, laboratories, classrooms (Kelly and Crawford 1997; Kelly and Green 1998). Rhetorical and linguistic analyses have already revealed some of the practices of particular disciplines (e.g. Myers 1990; Halliday and Martin 1993; Martin and Veel 1998). Because of the diversity of science and writing, student writing needs to be sensitive to site-specific features of the local educational and disciplinary contexts.

Finally, even though using evidence to support positions in science is considered central to science and valuable for learners, appropriate analytic tools are needed to display the use of generalization and specifics and their relationship within student writing. An earlier paper (Kelly and Takao 2002) introduced a task specific analytical tool for characterizing the epistemic level of statements in student papers, and the relationship of statements of different epistemic levels. In order to see how these epistemic relations fit into the structure of the argument and the web of evidentiary and conceptual terms deployed in a particular text, the current study brings the analysis of epistemic levels together with analyses of the rhetorical moves within the particular assignment genre and of the lexical strings that support text cohesion.

Educational setting

The study was conducted in an introductory oceanography course at the University of California, Santa Barbara. The instructor of the course has been consulting for several years with the two authors of this paper as part of his reflective development of this course and the software that supports the course activities. This paper is one of a number of studies that have grown out of the instructor's desire to understand how students can learn to act and think more like scientists and how course assignments and support materials can support students successfully engaging scientific practice. Because of the reflective, sophisticated design of the course and the particular character of oceanography, the course has several unusual features that bear on the study.

Oceanography is an inherently multidisciplinary science, drawing from physics, geology, chemistry, and several life sciences. It has rarely been examined in educational and social science studies and is a subject university students usually have little prior experience with in secondary school. Most of the approximately 200 students enrolled in this lower-division general education course during the term studied are not geological science majors. The stated objectives in the students' laboratory manual included giving students the experience of 'thinking like scientists' in addition to 'learning basic facts about the earth'. Students were informed that they will learn to 'develop some ability to think critically about science and scientific claims', 'gain skills in using the computer', and to use real earth data to make their 'own scientific judgments and conclusions' (Prothero 1998: 2).

The course curriculum emphasized the theory of plate tectonics. The focus on plate tectonics was educationally significant because of its theoretical centrality to geology and the development of this theory in the history of science: it provides an excellent example of the changing nature of scientific knowledge, the importance of interdisciplinarity, and the role of theory in the processes of conceptual change (Duschl 1990).

Writing was a key instructional component of this course. Designated as a 'writing intensive course' it required a one page (graded) pre-paper, with peer feedback in the lab sections, and a mid-term 'technical paper' typically 6–7 pages in length. The goals for this writing centred on engaging students with key elements of scientific practice including understanding relevant background knowledge (i.e. the theory of plate tectonics), asking researchable scientific questions, selecting data and making observations relevant to the question posed, interpreting data to support a theory or model, presenting an argument, and evaluating the work of others. This mid-term technical paper counted for 30 per cent of a student's final grade for the course. The writing was supported by the course lectures, the laboratory sessions, and an interactive CD-ROM developed to provide access to real earth data sets organized in geographical and conceptual ways.

Each week, the students attended three one-hour lectures, offered by the course professor, and one two-hour laboratory session of approximately 20 students, led by graduate student teaching assistants. The laboratory room had 25 Macintosh power PC computers with CD-ROM drives, and an AppleShare file server, all dedicated to the course. Students in this course used an interactive CD-ROM, 'Our Dynamic Planet', which included a variety of instructional resources and activities. A major component most relevant to the current study is access to earth data sets as a basis for solving problems associated with plate tectonics (Prothero 1995). The data sets are displayed on maps of various magnification, by which students can plot earthquake locations and cross-sections, seafloor elevation cross-sections, cenozoic volcano locations (on land). They can also determine island ages and measure heat flow as well as access movies and still graphics concerning particular locations. Data of this sort allowed students to pose questions, consider relevant evidence, evaluate hypotheses, and illustrate the theory of plate tectonics. Plate boundary types could be identified through earthquake, volcano, elevation, and heat flow analyses; and plate motion velocities could be identified through consideration of island ages and hot spots.

The technical scientific paper examined here drew from these data sources to characterize specific geographical sites in terms of the theory of plate tectonics. The students were instructed to formulate arguments characterizing plate boundaries and motion. The assignment included suggestions about the relationship of this assignment to previous work, uses of evidence for plate tectonics, and developing arguments based on geophysical evidence. (A complete text of the writing prompt is provided in the Appendix.) Thus, the academic task required students to ground theoretical assertions upon relevant data. While the move to greater levels of abstraction is typical of processes of scientific argument (Latour 1987; Knorr-Cetina 1995), this course provided specific support and focus on these discursive practices of science.

The scientific genre and more detailed aspects of the argument to be produced by students was specified through instructional episodes dedicated to scientific writing, through a detailed set of instructions and examples provided in a laboratory manual, and through peer and instructor feedback on student writing. The course lectures and laboratory sessions included discussions covering such topics as how scientists select a problem, how evidence is used to support a theory or model, how observations are separated from interpretations, how these elements are formatted into a scientific paper, and how to generate and use feedback from other writers (see Kelly and Takao 2002; Kelly *et al.* 2000). The course laboratory manual offered students instructions and examples of the sort of writing expected of them. This manual presented the students with the expected format of a technical scientific paper including the different sections—listed as abstract, introduction, methods, observations, interpretations, conclusions, figures and captions, references. Each of these sections was described and illustrated by examples. The task of writing a technical scientific paper was additionally supported by a similar, but shorter, 'pre-paper' task for which students received feedback from both their fellow students and graduate student teaching assistants.

Earlier studies of previous iterations of this course in which the first author of this study participated have examined the framing of oceanography through instruction by the course professor and teaching assistants, the formulation of written scientific arguments by the students, and interviews with instructors and students concerning the assessment of evidence in student writing (Kelly *et al.* 2000; Kelly and Takao 2002; Takao and Kelly 2001). The first study (Kelly *et al.* 2000) identified ways teachers and students came to define particular views of disciplinary knowledge through the everyday practices associated with teaching and learning oceanography. Specifically, two thematic stances toward scientific writing emerged in the course: (a) writing in science was presented as a practice that required an understanding of the reasons, uses, and limitations of written knowledge specific to the discipline; and (b) writing in science was presented as being shaped by a community's procedures, practices, and norms. While this study identified social practices associated with inquiry and writing in science, there nevertheless remained questions about the students' perspective on such issues and the students' appropriation of the presented practices in their own writing.

The second study introduced an initial analytic to assess the university oceanography students' use of evidence in writing (Kelly and Takao 2002). Drawing from rhetorical studies of science writing and studies of argumentation in science education, a model for assessing students' arguments was used to analyse the relative epistemic status of propositions in students' written texts. Each student's use of statements of varying epistemic level was compared with holistic assessments of the writing by the professor and the teaching assistants. Results were then compared across the 24 students' papers analysed. Argumentation analysis, focusing on the epistemic level of claims, identified features of students' appropriation of scientific discourse, but left unanswered key questions concerning the inference logic and reasoning chains in the formulation of scientific argument. By considering the epistemic level of claim without identification of how these claims were bound together in a larger argument, Kelly and Takao (2002) could account for only part of the overall rhetorical task. Thus, new methodological procedures are required for further specification of student engagement in scientific reasoning through writing in this genre—procedures we elaborate in the current study.

A third study examined differences in how populations with different geological knowledge assessed evidence in student writing. This study used clinical interviews—professional conversations oriented to ascertain the nature and extent of an individual's knowledge within a given domain (Posner and Gertzog 1982)—with course instructors (professor and graduate student teaching assistants), oceanography students, and a sample of undergraduate students not enrolled in the course. In this case, the interviews sought to assess the interviewees' views regarding the writing of a high scoring paper and a low scoring paper from a previous academic year. Through these interviews Takao and Kelly (in review) found that while all three populations were able to recognize distinct differences between the two papers, their reasoning for such differences were rather inchoate. Only the course professor could articulate the key differences in the argumentation structure for the student high scoring and low scoring papers, particularly concerning the use and relationship of statements of different epistemic levels. The other interviewees (i.e. graduate student instructors, oceanography students, and non-science undergraduates) showed little difference in articulating reasons for variation in quality of science writing and were not able to identify key features leading to success. To demystify these textual features we propose new methodological procedures for analysis in the current study to consider the rhetorical moves and lexical cohesion, in addition to variations in the epistemic level of claims in argument.

METHODS

For this study we chose the paper rated highest by the course professor from each of two previous studies (Kelly and Takao 2002; Takao and Kelly 2001). Through an in-depth and detailed analysis we sought to identify the linguistic forms and reasoning processes embedded in student writing concerning scientific evidence.

Argument theory, in the traditions of both classical authors (e.g. Aristotle 1991) and contemporary (e.g. Toulmin 1958), has often considered the extent to which an author's claims are persuasive for a given audience (Ramage *et al.* 2001; van Eemeren *et al.* 1987). In previous analyses of university oceanography students' written argument, Kelly and Takao (2002) proposed an argumentation model that extended Toulmin's layout of argument to include a consideration of the various epistemic levels of claims (Kelly and Chen 1999; Latour 1987; Myers 1990). This model was loosely based on the spectrum of transactive functions proposed in Britton *et al.* (1975) and on Latour and Woolgar's (1979) modality of claims, but then applied to the specific conceptual and evidentiary domain invoked by the assignment. This model identified certain features of the students' argument (e.g. distribution of claims across levels of generality) and the relationship of component parts to overall argument strength (e.g. ratio of theoretical claims to data representations). However, a number of questions were left unresolved: how are claims at various epistemic levels related to overall coherence? How does the structure of the written argument vary across subsections, given the differing rhetorical purposes? What sorts of rhetorical moves are required to accomplish the task of producing written scientific argument? Finally, how are the rhetorical moves, epistemic levels, and elements of cohesion related to one another? These questions provided motivation for the present study, but required additional methodological procedures. This more in-depth analysis of papers viewed as excellent by the subject matter specialist (course professor) shows the detailed mechanisms of building arguments that bring together theoretical generalizations with specific data within the rhetorical moves of the argument and through the lexical cohesion that ties the referents of the text together.

The detailed study of exemplary texts in order to understand the nature of scientific argument follows long-standing traditions in science studies and the rhetoric of science. The empirical study of scientific practices looking at individual cases has led to a burgeoning of insights regarding the scientific enterprise (Jasanoff *et al.* 1995; Roth *et al.* 1996). Among the productive methods used to examine these individual cases have been the rhetorical and linguistic analysis of spoken and written discourse (e.g. Garfinkel *et al.* 1981; Goodwin 1995). For example, Myers' (1990) study of the transformation of two biology texts considered how the extent of the claims made by the scientist authors was tempered through negotiations with reviewers and editors. The specialty of the rhetoric of science in particular has combined studies of larger bodies of texts with detailed analyses of individual texts, as in the work of the current second author (Bazerman 1988, 1993, 1999).

In the current study, since we are examining the skilled performance of students within the assignment and pedagogical structure of the course, our focus is specifically on the written product that counts as a token of successful practice. While important questions may be asked about what personal characteristics, processes of writing, orientations toward the assignment, or learning experiences may have facilitated this successful performance, those are not the questions we are addressing here. Nor are we addressing here the serious ethical and motivational issues of socializing students into disciplines or coercing them to temporarily adopt superficial modes of disciplinary behaviour. We adopt here, rather, a very narrow focus in simply asking, all those other questions aside, what constitutes successful performance. In this way we are following a different path than such valuable studies of student writing across the curriculum as Chiseri-Straiter (1991), Herrington (1985), Herrington and Curtis (2000), and McCarthy (1987). To identify the features that characterize papers considered to successfully realize the genre of the assignment, we examine the rhetorical, semantic, and epistemic dimensions of two student responses to the assignment. We recognize that additional work is needed to establish our findings as indicating more general features of successful writing within the particular course, for other undergraduate writing courses, and in other disciplines. Thus, the generalizability of our results remains an open question for further inquiry.

Our initial analysis consisted of three central components and their possible interactions. For each of the two student papers we entered each sentence verbatim into a spreadsheet from the six pre-specified sections of the papers: abstract, introduction, methods, observations, interpretations, and conclusion. We then proceeded with the three initial analyses. Figure 1 shows the eight sentences and associated analyses for one student's (Randy's) abstract.

Our first analysis considered the rhetorical moves made by the student authors to accomplish their writing task. This analysis was based loosely on Swales (1990), *Genre Analysis*. Following Swales, we identified what seemed to be characteristic moves the author makes within each section of the essay to realize the function of that section. In identifying moves, we were also guided by the required sections and advice provided by the prompt and lab book. For example, Figure 1 shows three rhetorical moves made by the student writer, Randy, in the eight sentences comprising his abstract: 'stating the problem' (sentences 1–2), 'setting central constructs in thesis statement' (sentences 3–7) and 'stating the central thesis' (sentence 8). Examination of the rhetorical moves across the length of the papers allowed for identification of the rhetorical commonplaces (Swales 1990). Since we are working with only two examples here these characterizations can be considered at best speculative and heuristic. They hardly yet can count as a pattern and represent at most what a first guess at a pattern might be.

Our second analysis consisted of identifying the level of generality of claim.

Rhetorical moves	#	Randy's sentences for paper ABSTRACT	C	I	II	III	IV	V	VI	lexical cohesions	cohesion notes
stating the problem	1	The study of plate tectonics involves understanding the certain characteristics involved in each type of plate boundary.							•	1 2 3 9 45 56 59 61 62 65 66 68 69 71 72 74 79 80 82 83	repetition (plate)
										1 9 58 80	repetition (tecton-)
										1 9	repetition (plate tecton-)
										1 2 3 4 9 31 45 46 55 56 57 59 61 68 69 79 80 82 83 87	repetition (boundar-)
	2	Looking specifically at the Aleutian Islands in the northern Pacific Ocean and the lower portion of the Mid Atlantic Ridge in the Atlantic Ocean, it is possible to identify two different types of plate boundaries.					•			2 5 11 29 56 68 80 81	repetition (Aleutian islands)
										2 11 29 65	repetition (Pacific)
										2 3 11 15 18 29 51 61 71 72 73 76 84	repetition (ocean-)
										2 11 29	repetition (Pacific ocean)
										2 6 8 11 45 69 75 77 79 80 85 86	repetition (Atlantic)
										2 4 6 8 11 45 47 48 51 52 53 54 63 69 71 72 73 75 77 78 79 80 83 85 86	repetition (ridge)
										2 6 8 11 45 69 75 77 79 80 83 85 86	repetition (mid atlantic ridge)
										1 2 3 9 45 56 59 61 62 65 66 68 69 71 72 74 79 80 82 83	repetition (plate)
										1 2 3 4 9 31 45 46 55 56 57 59 61 68 69 79 80 82 83 87	repetition (boundar-)
Setting central constructs in thesis statement	3	Characteristics involved with a subduction zone, or convergent boundary, are earthquakes occurring at all depths, volcanic activity, and a-deep ocean trench at the boundary between the plates.						•		3 5 13 62 63 65 68 81 87	repetition (subduct-)
										3 5 13 63 87	repetition (zone)
										3 9 61 68 82 83	repetition (convergen-)
										1 2 3 4 9 31 45 46 55 56 57 59 61 68 69 79 80 82 83 87	repetition (boundar-)
										3 4 14 19 22 32 33 41 42 43 46 52 58 59 61 65 74 81 84	repetition (earthquake)
										3 22 23 42 49 59 66 75	repetition (depth)
										3 4 6 7 14 25 26 28 37 52 61 63 67 81 85 86	repetition (volcan-)
										3 35 39 61 65 81	repetition (deep-)
										2 3 11 15 18 29 51 61 71 72 73 76 84	repetition (ocean-)
										3 34 35 37 39 41 43 60 61 62 63 67	repetition (trench)
										1 2 3 9 45 56 59 61 62 65 66 68 69 71 72 74 79 80 82 83	repetition (plate)
	4	Things to look for to identify a region with seafloor spreading, a divergent boundary, are shallow earthquakes, volcanic activity, and topography that shows a ridge where the spreading is originating from.						•		4 14 28 39	repetition (region)
										4 8 13 27 70 73 76 77 79 84 87	repetition (seafloor)
										4 8 13 20 27 70 74 79 83 84 87	repetition (spreading) repetition (seafloor
										4 8 13 27 70 79 84 87	
										4 6 9 28 86	repetition (diverg-)
										1 2 3 4 9 31 45 46 55 56 57 59 61 68 69 79 80 82 83 87	repetition (boundar-)
										3 4 14 19 22 32 33 41 42 43 46 52 58 59 61 65 74 81 84	repetition (earthquake)
										3 4 6 7 14 25 26 28 37 52 61 63 67 81 85 86	repetition (volcan-)
										4 14 16 35 38 51 81 84	repetition (topograph-)
										2 4 6 8 11 45 47 48 51 52 53 54 63 69 71 72 73 75 77 78 79 80 83 85 86	repetition (ridge)
Stating thesis statement 1	5	The Aleutian Islands exhibit all the qualities of a subduction zone so it is therefore safe to assume that this is what is taking place there.					•			2 5 11 29 56 68 80 81	repetition (Aleutian is.)
										3 5 13 62 63 65 68 81 87	repetition (subduct-)
										3 5 13 63 87	repetition (zone)
Setting central constructs in thesis statement	6	The Mid Atlantic ridge has each of these divergent qualities except for the volcanic activity.					•			2 6 8 11 45 69 75 77 79 80 85 86	repetition (Atlantic)
										2 4 6 8 11 45 47 48 51 52 53 54 63 69 71 72 73 75 77 78 79 80 83 85 86	repetition (ridge)
										2 6 8 11 45 69 75 77 79 80 83 85 86	repetition (mid atlantic ridge)
										3 4 6 7 14 25 26 28 37 52 61 63 67 81 85 86	repetition (volcan-)
	7	This is due to the fact that the data available doesn't include many underwater volcanoes.				•				7 15 16 17 19 21 28 52 85 86	repetition (data)
										3 4 6 7 14 25 26 28 37 52 61 63 67 81 85 86	repetition (volcan-)
Stating thesis statement 2	8	Regardless of this fact, it can still be stated that the Mid Atlantic Ridge is an area of seafloor spreading.					•			2 6 8 11 45 69 75 77 79 80 85 86	repetition (Atlantic)
										2 4 6 8 11 45 47 48 51 52 53 54 63 69 71 72 73 75 77 78 79 80 83 85 86	repetition (ridge)
										2 6 8 11 45 69 75 77 79 80 83 85 86	repetition (mid atlantic ridge)
										8 13 14 27 29 30 31 32 37 40 45 46 51 52 55 58 70 81 82	repetition (area)
										4 8 13 27 70 73 76 77 79 84 87	repetition (seafloor)
										4 8 13 20 27 70 74 79 83 84 87	repetition (spreading) repetition (Seafloor
										4 8 13 27 70 79 84 87	

Figure 1: Analysis of eight sentences comprising Randy's abstract. Analysis of this sort was done with the Microsoft Excel spreadsheet program

We took the sentence as the unit of analysis. In those cases where compound sentences made claims at multiple levels we chose to code the sentence at the highest epistemic level. There were seven epistemic levels, six of which represent a continuum from specific data-pointing claims (level I) to more general theoretical claims (level VI). Level 'C' refers to personal or other meta-discoursal comments made by the author (e.g. 'Living in California, we have a personal stake in the study of plate tectonic theory.'). The categories of epistemic generality are subject-matter specific, in this case directly derived from geological description and theory. Further, the epistemic categories were developed in relation to this specific assignment and not across a range of geologic arguments and thus must be understood as assignment-specific as well as subject-matter specific. The six categories are as follows: representations of data; identification of topographical features; relational aspects of geological structures; data illustrations of the authors' geological theories or models; authors' proposed geological theory or model; general description of geological processes and references to definitions, experts, and textbooks. (Further details of the epistemic levels analytic are available in Kelly and Takao (2002).) Figure 1 shows the seven epistemic levels in columns four to ten, with each sentence marked at a particular level.

A third analysis concerns the ways the students' arguments cohere, particularly in bringing together specifics and generalizations. While coherence is ultimately a matter of readers' construction of meaning, perhaps from subtle textual hints, it is aided by several formal linguistic techniques of cohesion. Cohesion refers to ways in which the 'interpretation of some element in the discourse is dependent on that of another' (Halliday and Hasan 1976: 4). These include such features as indexical references (e.g. 'this'), conjunctions, substitutions (e.g. pronouns), ellipsis, and lexical cohesion. Lexical cohesion, more particularly, refers to interdependent semantic relationships among words—that is, the ways words and related words repeat and chain throughout the text. Based on the work of Halliday and Hasan (1976) and Hoey (1983, 1991), we identified the anaphoric (backward-pointing to a prior referent) and cataphoric (forward-pointing to future appearances) lexical cohesions. Our specific focus was on reiteration, the repeating use of the same word or word root (e.g. volcano, volcanic). In addition we considered collocation, the association of lexical items that regularly co-occur (e.g. plate and tectonic). The column labelled 'Lexical Cohesions' of Figure 1 identifies the sentence number and all other sentences that share some lexical cohesion. Notes in the final column identify the type of cohesion. For example, sentence 1 shows reiteration cataphorically through repetition with 'plate' (to sentences 2, 3, 9, 45, 56, 59, 61, 62, 65, 66, 68, 69, 71, 72, 74, 79, 80, 82, 83), with 'tecton-' (to sentences 9, 58, 80), and with 'boundar-' (to sentences 2, 3, 4, 9, 31, 45, 46, 55, 56, 57, 59, 61, 68, 69, 79, 80, 82, 83, 87). In addition, there is a cataphoric cohesion with the compound 'plate tecton-' to sentence 9, and collocation between 'plate' and 'boundar-' (to sentences, 2, 3, 9, 45, 56, 59, 61, 68, 69, 79, 80, 82, 83).

We treat as distinct lexical items synonymous terms (e.g. earthquake, tremor, seismic). We also did not consider indexical pronominal references (e.g. 'these' referring to specific earthquakes) as lexically cohesive with the original term. There was no use of dual meanings assigned to single lexical forms. Within this sample terms were used univocally and explicitly. We have not, however, studied this interesting phenomenon and how it might be related to the technicality of the writing task or the state of student knowledge. This consistent use of terminology lends validity to the analysis of lexical cohesion. Semantic meanings and lexical forms in this case have a high degree of convergence. Such convergence would not pertain in domains where related meanings are represented through multiple lexical forms.

RESULTS OF TEXTUAL ANALYSIS OF STUDENTS' WRITTEN ARGUMENTS

The research findings are organized into three sections. First, we present our analysis of the students' rhetorical moves. Second, we present the results of the analysis of the epistemic level of claim by the student authors. Third, we present analyses of the lexical cohesions used by the student writers and consider the ways that the overall arguments cohere. Through this presentation we note salient interactions of the three analyses.

Rhetorical moves

Each of the students used a set of rhetorical moves to accomplish the writing task. These are presented in Figure 2. Since these attributed moves are based on only two cases, they have little persuasive force beyond their general plausibility and their relation to the assignment prompt and supporting instructor-provided guidelines. However, their similarity to and focused differences from typical patterns found in other scientific and educational genres suggest some observations which might be confirmed in a broader sample, as follows.

Since the paper is situated within a well-defined knowledge space of a specific undergraduate course, the introductory section, in order to establish the field, presents the central constructs drawn from the course to be used in the paper rather than providing a review of the literature. Since this text also serves to display and rehearse student knowledge, the students need to define and explain the central constructs beyond the need of the readers to understand material in order to assure the instructor of the students' learning.

Since the typical aim of the school paper (as distinguished from a professional article) is to argue a thesis in resolution of the problem set in the classroom (a well-identified puzzle, rather than a previously unknown or author-selected problem whose value must be motivated for the audience) the last move of the introduction is to establish a central thesis rather than to identify the contribution of the current work. This central thesis employs the central constructs and applies them to the specifics examined in the paper. Also, in light of the exigencies of school assignments, we might consider the novelty of the paper not as in its contribution to the discipline but in the cleverness of the particular problem identified and addressed by the student. That is, the transformation of the basic problem/puzzle into a cleverer one allows the student to develop a more complex argument, draw on a wider body of relevant data and display deeper reasoning—this is another area to be investigated in a future paper.

In addition, the consideration of the rhetorical moves within a section of the student paper (e.g. abstract, introduction, methods, etc.) has implications for our subsequent analyses of epistemic level of claim and lexical cohesion. For example, the rhetorical move of ‘identifying the central constructs’ to be developed and specified by the subsequent empirical information suggests that the student authors need to begin at a certain level of generality for each section prior to offering details filling in the overall picture. Consequently, patterns in the epistemic level of claim may emerge as the student authors move from introductory text beginning each section to the exposition of the substantive points. In addition, the early-introduced central constructs may have a presence throughout the papers but in varying ways depending on the specific rhetorical task of the subsequent text. Thus, the analysis of the rhetorical moves provided one way of tying the three analyses into an overall depiction of the students’ adherence to scientific argument as specified by the genre of this course assignment.

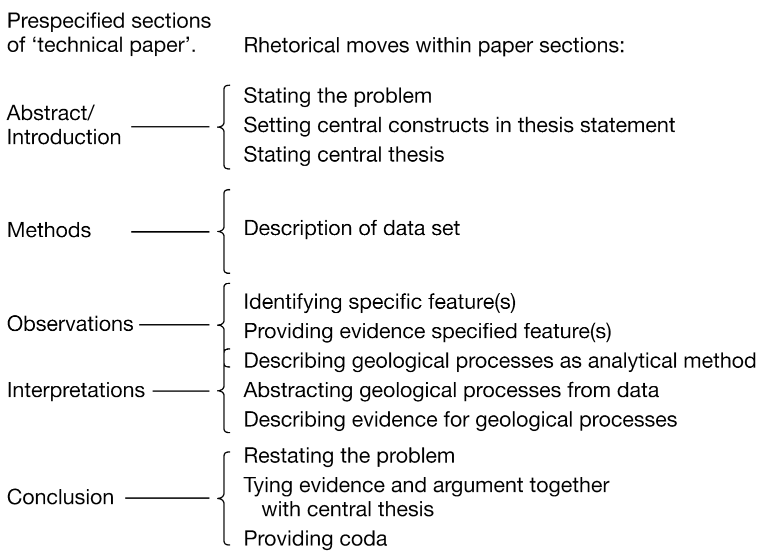

Figure 2: Student rhetorical moves used to accomplish tasks associated with technical paper genre

Epistemic level of claim

The second analysis focused on the level of claim being made by students in each of the sentences. The analysis of the multiple epistemic levels of claims used by the students shows some interesting patterns. Figures 3 and 4 show the epistemic level of each of the sentences in each of the papers, 1 and 2 respectively. The general contour of the epistemic levels for both papers follows a high–low–high pattern: The introductory remarks in the 'abstract' and 'introduction' sections and the final remarks in the 'interpretations' and 'conclusions' sections show high levels of claim. These claims are thus more general in nature establishing the theoretical knowledge that organizes the argument. The lower-level claims, i.e. referring to more specific features of the data or methods of investigation, are found in the 'methods' and 'observations' sections.

There are two features of the data related to epistemic levels worth mentioning. First, the students generally understood the task as articulated in the course laboratory manual and through classroom discourse. As instructed, the students kept the research methods and observations to relatively low-level descriptive comments about their procedures and data representations. They reserved the broader theoretical discussion for framing the problem (in the introductory sections), making ties of theory to data in the interpretations, and resolving the thesis in the conclusion. Second, the matching of the epistemic levels (Figures 3 and 4) and the rhetorical moves (Figure 2) similarly identified how students were able to pitch the differing rhetorical moves at different epistemic levels, thus effectively framing and communicating theoretical arguments at various degrees of specificity. For example, theory-framing moves (e.g. stating/restating the problem, stating thesis) operated at relatively high epistemic levels (e.g. levels 4–6: data illustrations of the authors' geological theories or models, authors' proposed geological theory or model, general description of geological processes and references to definitions, experts, and textbooks). The rhetorical moves within the methods and observations sections focused on description of methods and geological features as well as identification and presentation of relevant evidence.

Lexical cohesion

Our analysis of lexical cohesion centred on the repetition of key constructs (Halliday and Hasan 1976) throughout the parts of the student papers. One student author averaged 57 lexical cohesions per sentence across the 99 sentences in his paper, while the other author averaged 44 lexical cohesions per sentence across the 87 sentences (see Table 1). As stated in our methods section, we do not purport to analyse coherence through our cohesion count. Our purpose for analysing lexical cohesion in this manner was to examine cohesion in relationship to the structure of the argument and the epistemic

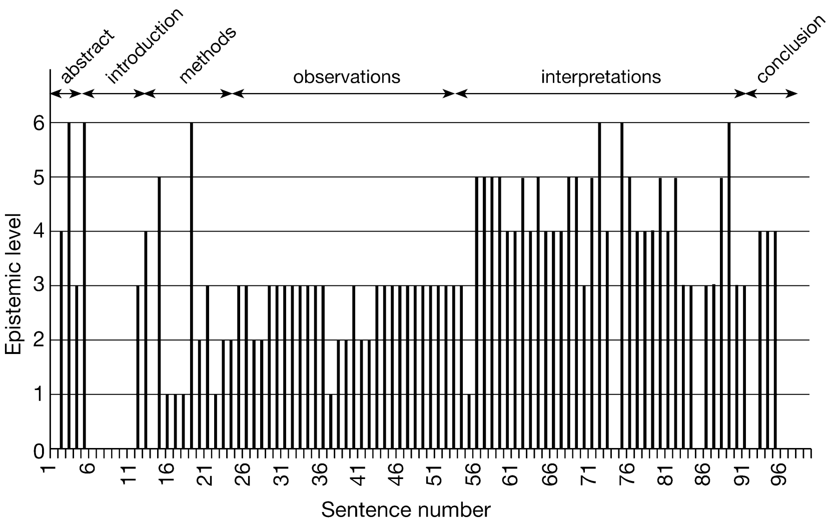

Figure 3: Epistemic levels of Nick's (student 1) propositions across sections of the paper

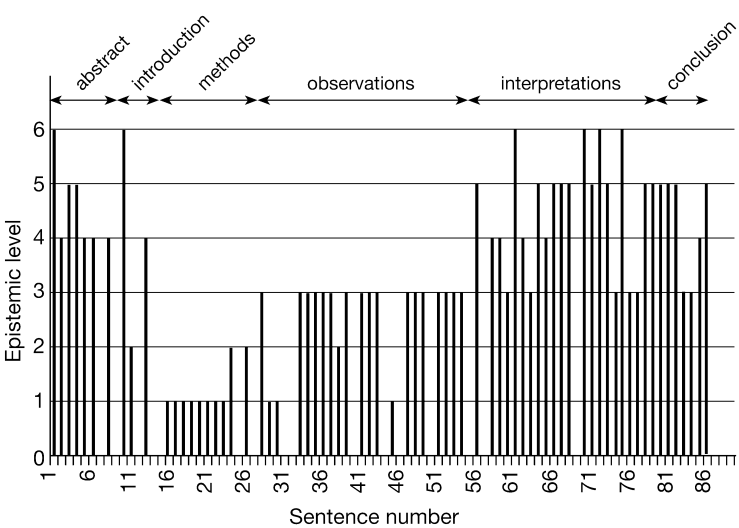

Figure 4: Epistemic levels of Randy's (student 2) propositions across sections of the paper

Table 1: Number of sentences, lexical ties, and lexical cohesion density for two student papers

Technical paper	Sentences		Lexical ties*		Lexical cohesions per sentence	
Sections	Paper 1	Paper 2	Paper 1	Paper 2	Paper 1	Paper 2
Abstract	4	8	244	588	61	73.5
Introduction	9	6	317	238	35.2	39.7
Methods	12	14	397	309	33.1	22.1
Observations	30	27	1862	891	62.1	33
Interpretations	37	24	2304	1215	62.3	50.6
Conclusions	7	8	496	604	70.1	75.5
Totals	99	87	5620	3845	56.8	44.2

* This figure was calculated by summing the lexical ties for each sentence. On Figure 1, these would mean summing the instances in the 'lexical cohesions' column.

levels of claims. In particular, we were interested in examining how claims of different epistemic level were bound together. Our analyses demonstrated a number of ways in which lexical cohesion served the rhetorical purposes of these authors.

The first analysis of lexical cohesion we present concerns how the authors introduced concepts and subsequently how these concepts echoed through the papers through reiteration. To consider how concepts were introduced and the role these concepts played across the length of the two papers we created the representations shown in Figures 5 and 6 (summaries of lexical cohesions organized by first mention). Figures 5 and 6 list the proposition number across the horizontal axis, organized by paper section, and list the key terms (showing multiple cohesions) ranked vertically by first mention. Figures 5 and 6 show interesting patterns across the two papers, both in terms of similarities and of differences. First, in both cases the terms introduced, either conceptual (plate-, boundar-, topograph-) or geographic (Aleutian islands, California-), in the first few sentences maintain their presence in the arguments throughout the length of the papers. There is an interesting difference in the two papers in terms of how new concepts are introduced. Paper 1, while introducing almost two dozen concepts in the first four sentences, continued to enter new ideas across the length of the paper. This use of new concepts can be attributed to the overall rhetorical strategy adopted by the author of uncovering a mystery. The author posed the initial problem of the paper as why California is considered on the 'ring of fire', yet

Section of paper -->	abstract			
proposition # -->	1	2	3	4
Key terms with multiple cohesions:				
area	1	2	3	
topograph-	1			
feature-	1			
volcan-	1		3	
seismic	1			
California-	1		3	
coast-	1		3	
California Coast (coast of CA)	1		3	
plate-		2	3	4
boundar-		2	3	
plate boundar		2	3	
geologist		2		
North American Plate		2		
Pacific		2		
Pacific Plate		2		
region			3	
data				4
tecton-				4
theory of plate tecton- (theory)				4
earthquake				
earth				
ridge				
profile-				
topographical profile				
elevation				
ocean-				
quake				
island				
Khamchatka				
trench				
deep-				
depth				
Pacific Ocean				
basin				
northwest-				
heat				
path				
Khamchatka coast				
Hawai-				
seamount				
island of Hawaii				
mountain				
continent-				
lithosphere				
mantle				
dense				
magma				
Kerile				
Kerile Trench				
converg-				
margin				
continental convergent margin				
crust				
southeast				
sediment				
(non)subduct-				
Kerile Coast				
hot spot				
transform				
fault				
transform fault				
San Andreas				

Section of paper -->	introduction								
proposition # -->	5	6	7	8	9	10	11	12	13
Key terms with multiple cohesions:									
area									13
topograph-									
feature-									
volcan-							11	12	13
seismic									
California-	5					10		12	13
coast-									13
California Coast (coast of CA)									13
plate-	5					10	11		13
boundar-									13
plate boundar									13
geologist						10			
North American Plate									
Pacific						10	11		13
Pacific Plate							11		13
region		6							
data									
tecton-	5					10			13
theory of plate tecton- (theory)	5					10			13
earthquake		6		8			11		
earth			7						
ridge				8					
profile-									
topographical profile									
elevation									
ocean-									
quake									
island									
Khamchatka									
trench									
deep-									
depth									
Pacific Ocean									
basin									
northwest-									
heat									
path									
Khamchatka coast									
Hawai-									
seamount									
island of Hawaii									
mountain									
continent-									
lithosphere									
mantle									
dense									
magma									
Kerile									
Kerile Trench									
converg-									
margin									
continental convergent margin									
crust									
southeast									
sediment									
(non)subduct-									
Kerile Coast									
hot spot									
transform									
fault									
transform fault									
San Andreas									

Section of paper -->	methods											
proposition # -->	14	15	16	17	18	19	20	21	22	23	24	25
Key terms with multiple cohesions:												
area	14			17								
topograph-			16									
feature-												
volcan-		15				19	20	21				
seismic									22			
California-		15										
coast-												
California Coast (coast of CA)												
plate-	14	15										
boundar-												
plate boundar												
geologist												
North American Plate												
Pacific												
Pacific Plate												
region												
data	14	15	16	17	18	19	20		22	23		
tecton-	14	15										
theory of plate tecton- (theory)	14	15										
earthquake		15							22			
earth												
ridge								21				
profile-		15	16									
topographical profile			16									
elevation			16									
ocean-				17				21				
quake										23		25
island												25
Khamchatka												
trench												
deep-												
depth												
Pacific Ocean												
basin												
northwest-												
heat												
path												
Khamchatka coast												
Hawai-												
seamount												
island of Hawaii												
mountain												
continent-												
lithosphere												
mantle												
dense												
magma												
Kerile												
Kerile Trench												
converg-												
margin												
continental convergent margin												
crust												
southeast												
sediment												
(non)subduct-												
Kerile Coast												
hot spot												
transform												
fault												
transform fault												
San Andreas												

Section of paper -->	observations																													
	<—— Kurile Trench region ——>											<-Hawaiian Islands&Emperor Seamo											<— California Coast —>							
proposition # -->	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55
Key terms with multiple cohesions:																														
area				29																										
topograph-	26								34	35			38		40									49		51	52	53		
feature-	26						32																							
volcan-	26					31		33																49						
seismic																					46									
California-																							48		50			53	54	
coast-	26	27								35													48			51			54	
California Coast (coast of CA)																													54	
plate-												37																		
boundar-																														
plate boundar																														
geologist																														
North American Plate																														
Pacific				29								37											48	49				53		
Pacific Plate												37																53		
region	26																													
data																														
tecton-																														
theory of plate tecton- (theory)																														
earthquake										35										45									54	55
earth																						47							54	
ridge																														
profile-	26			29	30	31	32		34	35	36		38		40	41	42	43	44					49		51	52	53	54	
topographical profile									34	35			38											49		51	52	53		
elevation																41	42		44								52	53		
ocean-	26			29					34														48	49		51	52	53		
quake																														
island												37	38	39	40			43	44	45	46									
Khamchatka	26									35																				
trench	26	27	28	29	30	31	32	33	34	35	36												48							
deep-			28																											
depth			28								36																			
Pacific Ocean				29																			48	49				53		
basin				29		31		33																			52			
northwest-					30								38		40		42	43			46									
heat									34										44											
path									34	35	36								44									53	54	
Khamchatka coast										35																				
Hawai-												37		39		41		43	44	45	46									
seamount												37	38																	
island of Hawaii														39				43	44	45										
mountain																										51		53		
continent-																										51				
lithosphere																														
mantle																														
dense																														
magma																														
Kerile																														
Kerile Trench																														
converg-																														
margin																														
continental convergent margin																														
crust																														
southeast																														
sediment																														
(non)subduct-																														
Kerile Coast																														
hot spot																														
transform																														
fault																														
transform fault																														
San Andreas																														

Section of paper -->	interpretations																																				
					<——— Kurile Trench region ———>														<-Hawaiian Is. & Emp. Smts									<——— California Coast ———>									
proposition # -->	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92
Key terms with multiple cohesions:																																					
area	56	57			60															75			78														
topograph-							62		64																			83									
feature-																																					
volcan-	56						62				66		68		70								78	79	80			83		85							
seismic							62										72										82										
California-	56																											83				87			90		
coast-	56				60			63	64					69				73										83	84								
California Coast (coast of CA)	56																											83									
plate-	56	57	58	59	60	61	62		64				68	69		71	72	73	74				78								86	87	88	89	90		
boundar-																																87					
plate boundar																																					
geologist					60												72			75																	
North American Plate							62							69				73														87	88				
Pacific		57					62												74			77	78									87	88				
Pacific Plate		57																	74				78									87	88				
region																														85							
data									64									73																			
tecton-	56																		74												86						
theory of plate tecton- (theory)	56	57																	74												86						
earthquake																71	72	73										83							90	91	
earth																																					
ridge																																					
profile-																		73										83	84								
topographical profile																												83									
elevation																								79		81											
ocean-						61		63		65	66											77							84								
quake																																				91	92
island																			74			77				81	82										
Khamchatka					60							67		69																							
trench					60		62		64		66																										
deep-										65							72	73																			
depth																																					92
Pacific Ocean																						77															
basin								63					68		70														84								
northwest-							62												74				78									87					
heat										65	66	67														81											
path																		73								81											
Khamchatka coast					60																																
Hawai-																						77			80	81	82										
seamount																			74			77															
island of Hawaii																										81											
mountain																													84								
continent-					60	61	62	63			66					71																					
lithosphere			58	59																	76																
mantle			58	59						65																											
dense				59				63																													
magma				59							66	67									76						82										
Kerile					60		62		64		66			69				73																			
Kerile Trench					60		62				66																										
converg-					60		62									71	72											83									
margin					60		62		64							71																					
continental convergent margin					60		62									71																					
crust						61		63			66					71	72										82										
southeast							62																										88				
sediment								63			66																										
(non)subduct-									64	65			68	69		71	72										82						88				
Kerile Coast									64					69				73																			
hot spot																				75	76	77	78		80												
transform																																		89	90		
fault																																		89	90	91	92
transform fault																																		89	90		
San Andreas																																			90		92

Section of paper -->	conclusion						
proposition # -->	93	94	95	96	97	98	99
Key terms with multiple cohesions:							
area				96			
topograph-				96			
feature-				96			
volcan-		94		96			
seismic							
California-	93	94	95			98	99
coast-	93		95			98	
California Coast (coast of CA)	93					98	
plate-	93		95	96		98	
boundar-			95				
plate boundar			95				
geologist							
North American Plate			95				
Pacific			95	96			
Pacific Plate			95	96			
region		94					
data	93						
tecton-	93						
theory of plate tecton- (theory)	93						
earthquake							
earth							
ridge							
profile-							
topographical profile							
elevation							
ocean-							
quake							
island							
Khamchatka							
trench							
deep-							
depth							
Pacific Ocean							
basin							
northwest-			95	96			
heat							
path							
Khamchatka coast							
Hawai-							
seamount							
island of Hawaii							
mountain							
continent-							
lithosphere							
mantle							
dense							
magma							
Kerile							
Kerile Trench							
converg-							
margin							
continental convergent margin							
crust							
southeast			95				
sediment							
(non)subduct-							
Kerile Coast							
hot spot							
transform			95				
fault		94	95	96			
transform fault			95				
San Andreas							

Figure 5: Summary of lexical cohesions organized by first mention for student 1 (Nick)

Section of paper -->	Abstract								Introduction						Methods													
proposition # -->	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Key terms with multiple cohesions:																												
plate-	1	2	3						9																			
tecton-	1								9																			
boundary(ies)	1	2	3	4					9																			
Aleutian Islands		2			5						11																	
island		2			5						11																	28
Pacific		2									11																	
ocean		2	3								11				15			18										
Atlantic		2				6		8			11																	
ridge		2		4		6		8			11																	
Mid Atlantic Ridge		2				6		8			11																	
subduct-			3		5								13															
zone			3		5								13															
converg-			3						9																			
earthquake(s)			3	4										14					19			22						
depth			3																			22	23					
volcan-			3	4		6	7							14											25	26		28
deep-			3																									
trench			3																									
region				4										14														28
seafloor				4				8					13														27	
spread-				4				8					13							20							27	
seafloor spreading				4				8					13														27	
diverg-				4		6			9																			28
topograph-				4										14		16												
data-							7								15	16	17		19		21							28
area								8					13	14													27	
feature(s)													13															
profile-																16												
land																16										26		
sea																16										26		
siesmic																				20		22		24				
quake(s)																					21		23					
age																												28
mountain																												
surface																												
Walvis																												
magma																												

Section of paper -->	Observations																										
	<------------------------ Aleutian Islands ----------------																<----------- Mid-Atlantic Ridge -------										
proposition # -->	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55
Key terms with multiple cohesions:																											
plate-																	45										
tecton-																											
boundary(ies)			31														45	46									55
Aleutian Islands	29																										
island	29				33	34																	51		53		
Pacific	29																										
ocean	29																						51				
Atlantic																	45										
ridge																	45		47	48			51	52	53	54	
Mid Atlantic Ridge																	45										
subduct-																											
zone																											
converg-																											
earthquake(s)				32	33								41	42	43			46						52			
depth														42							49						
volcan-									37															52			
deep-							35				39																
trench						34	35		37		39		41		43												
region											39																
seafloor																											
spread-																											
seafloor spreading																											
diverg-																											
topograph-							35			38													51				
data-																								52			
area	29	30	31	32					37			40					45	46					51	52			55
feature(s)			31																								
profile-										38	39			42													
land								36	37																		
sea							35																				
siesmic																			47	48							
quake(s)															43						49						
age																									53	54	
mountain											39												51				
surface															43						49						
Walvis																										54	
magma																											

Section of paper -->	Interpretations																									Conclusion						
	<------------------ Aleutian Islands -----------													<----------- Mid-Atlantic Ridge ----------->																		
proposition # -->	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87
Key terms with multiple cohesions:																																
plate-	56			59		61	62			65	66		68	69		71	72		74					79	80		82	83				
tecton-			58																						80							
boundary(ies)	56	57		59		61							68	69										79	80		82	83				87
Aleutian Islands	56												68												80	81						
island	56						62																78		80	81						
Pacific										65																						
ocean						61										71	72	73			76								84			
Atlantic														69						75		77		79	80			83		85	86	
ridge								63						69		71	72	73		75		77	78	79	80			83		85	86	
Mid Atlantic Ridge														69						75		77		79	80			83		85	86	
subduct-							62	63		65			68													81						87
zone								63																								87
converg-						61							68														82	83				
earthquake(s)			58	59		61				65									74							81			84			
depth				59							66									75												
volcan-						61		63				67														81				85	86	
deep-						61				65																81						
trench					60	61	62	63				67																				
region																																
seafloor															70			73			76	77		79					84			87
spread-															70				74					79				83	84			87
seafloor spreading															70									79					84			87
diverg-																															86	
topograph-																										81			84			
data-																														85	86	
area			58												70											81	82					
feature(s)																																
profile-																																
land												67				71	72															
sea																																
siesmic																																
quake(s)					60															75												
age																					76		78									
mountain																																
surface										66	67					71			74													
Walvis																							78									
magma													67			71	72															

Figure 6: Summary of lexical cohesions organized by first mention for student 2 (Randy)

experiences earthquakes rather than volcanoes. Thus, while making the standard arguments regarding plate boundaries and movements, the author gradually introduced new ideas relevant to the ring of fire mystery. In the second paper a different pattern emerges. In this case approximately three-quarters of the 'key terms' listed in Figure 6 are introduced by the end of the introduction (sentence 14). In this case the author posed a more standard problem (characterizing plate boundaries) and focused on the details of accomplishing this task.

Second, sentences at the boundaries of the six paper sections (i.e., abstract, introduction, methods, observations, interpretations, conclusion) tended to include multiple terms with extensive lexical cohesions. For example, in paper 1, sentences 1, 5, 13–14, 26, 56, 93 included a relatively large number of terms (vertical columns in Figure 5) that cohere across multiple propositions (horizontal rows in Figure 5). The same pattern was found in paper 2 with sentences 1, 9, 15–16, 29, 56, 80. These 'boundary' sentences served the function of aggregating key ideas and developing a framework for the more detailed work that follows in each section. For example, in paper 1, sentence 26 reads:

> Three profiles taken along the coastal region of the Khamchatka Peninsula display the topographic features of an oceanic trench and the thousands of volcanoes that exist 200–400 km inland of the trench (fig.3).

This sentence reprised high abstraction terms of the introduction (topograph-, feature, volcan-) and then juxtaposed them with data category terms from the methods section (profile, ocean-). The author then added two specific terms that are to launch the specific data of the three observations in this section—and to reappear through this section (Khamchatka, trench), and to which were attached further data-specific terms in the ensuing sentences. Sub-launchings of each of the three separate observation regions in sentences 27 (Kurile Trench), 37 (Hawaiian Islands), and 48 (California coast) were then less cohesively dense, simply identifying the site of observations—the major integration of theory, features, and data resources having been done in the covering sentence 26. For example, sentence 27 reads:

> The trench lies at 60 deg. N latitude and 160 deg. E longitude and extends for 2,200 km in length along this coast.

The opening of the interpretation section returned to higher order concepts, but tied to the key problematic term of 'California coast' which formed a tight string throughout the interpretation section—to which were added new data and terms concerning tectonics and earth structure (lithosphere, mantle, margin, crust, etc.) which expanded the interpretation of the quake and volcanic data from the observations.

In the second paper in the observations section there was no general introduction sentence that covered the two cases explored, so that each observation and interpretation subsection was launched by a return to the higher level concepts introduced early in the paper, and then sunk down into the specifics observed (sentences 29–32: first region of investigation, the Aleutian Islands; sentences 45–47: second region of investigation, the mid-Atlantic ridge). The interpretation reaggregated the specifics with concepts, returning to higher level material first appearing in the introduction. The conclusion section operated on a high conceptual level, and had none of the later introduced concepts and data. In both papers the term 'data' was seriously launched at the introduction of the methods section (since the method involves the use of a database) which then intensely strung throughout that section but essentially vanished in the other sections as the general category of data became transformed into specifics of observations.

Third, in both papers, lower order terms (sequentially introduced later in the organizational structure) in the observations section showed fewer cohesions to the key constructs (that is, the first dozen or so terms introduced first and maintaining lexical ties throughout). This contrasts with the interpretation section where lower order terms were tied more directly to the key constructs through lexical cohesions. This pattern can be seen in Figures 5 and 6 in two ways. In both observations sections, the lexical ties for the higher order terms are relatively sparse. Second, in each of the interpretations sections there are long vertical strings, indicating that individual sentences tie together higher order constructs with lower order terms.

Fourth, in both papers the cohesive density per sentence varied in similar ways (see Table 1). For each of the authors the number of lexical ties per sentence (i.e. cohesive density) extended or contracted given the rhetorical tasks of the different sections of the papers. For example, the highest number of cohesions per sentence was found in the introduction and conclusion sections where the authors need to set/close their problem, draw on theoretical knowledge, and situate their particular study in an overall geological argument regarding plate tectonics. The methods sections showed the lowest number of ties per sentences, as the authors described the sources of their data and their methods of analysis.

DISCUSSION

The textual analyses we presented in this paper provide some general trends and point to some potential educational issues. We frame these as points for discussion as, of course, we do not wish to draw definitive conclusions from analyses of just two papers. These discussion points are framed in two ways. We present discussion of the findings of the analyses and then shift to how the analyses speak to educational issues.

Students' arguments and relevant knowledge

The analyses of the two papers made visible some features of the students' scientific writing. First, these papers (chosen as high quality by the instructors) were shown to be highly structured linguistic documents along several dimensions. In each case the students organized their texts in the following ways:

(a) The arguments showed a hierarchical arrangement within the logic of the genre structure, that is the students introduced and maintained the use of key conceptual terms (e.g. plate, tecton-, topograph-, boundary(ies)) as shown in Figures 5 and 6. These terms were combined with specific geographical terms (those locating the areas in question: e.g. California coast, Aleutian Islands) and a set of lower level terms (often conceptual such as island, trench, depth, mountain).
(b) Multiple cohesive links were formed across the majority of the sentences forming the complete argument set in the technical paper. These links often included a set of key conceptual terms, introduced within the first few sentences and maintained throughout the papers as evident in Figures 5 and 6.
(c) Sentences at the boundaries of sections and subsections tended to have denser cohesive links with other sections of the paper and tended to tie together semantic items of multiple epistemic levels.
(d) The epistemic status of the claims made varied according to the rhetorical needs of the differing sections, defined by the genre structure. The introduction, interpretations, and conclusions showed the greatest levels of generality (Figures 3 and 4).
(e) Often repeated terms built up cohesive density and thematic saliency as they were associated with other terms in different sections of the paper. For example, a term like 'plate' (for both papers, see Figures 3 and 4) was introduced as a theoretical term, subsequently associated with geographically specific terms (mid-Atlantic ridge, or Kurile trench), and then used in interpretations with revisited theoretical terms (tectonic).

These findings document the manifestation of some of the relevant conceptual, rhetorical, and linguistic knowledge needed to write geology in this technical genre. The detailed textual analysis thus provided ways of making the tacit knowledge of successful students explicit for teachers and students. The analyses can contribute to planning for instruction in technical writing as it provides a way to identify what is valued within the community of writers. This may provide ways for scientists (as teachers) and teachers of science to understand and articulate the valued practices. If teachers of technical writing are to demystify the writing process, then unpacking the epistemic and rhetorical features of successful argument provides one relevant tool.

Educational issues related to written argument

There are a number of potential educational implications, which we treat here as relatively speculative but worth considering none the less. First, as noted, the detailed analysis of student writing provides science teachers with material for reflection and choice making. While the graduate student teaching assistants possessed the subject matter knowledge and were able to recognize quality writing, they were less able to identify the features that qualify a text as high quality, as shown in a set of clinical interviews conducted as part of the larger ethnographic study (see Takao and Kelly 2001). One obvious application thus relates to the education of new science teachers in their assessment of student writing. In the university setting of this study, these new teachers are graduate geology students responsible for assessing, grading, and providing feedback to the student writers. The education of these educators of scientific writing can benefit from a review of the specific ways evidence is formulated, arguments made, and knowledge claimed. These graduate student instructors often do not study writing in a formal way in their own educational experiences—leading to our second implication.

A second issue we raise concerns the education of science students and science teachers. Few science students (and teachers) get a long and deep apprenticeship with writing. What instruction and practice they may have had in writing is likely to have been within the dominant literary and humanistic practices of language arts education. Furthermore, the genre conventions of scientific discourse have been shown to present significant obstacles for students (Halliday and Martin 1993; Lemke 1990)—perhaps even more than other specialized discourses, at least at the entry level because of the obvious strangeness of the language. That very strangeness, however, makes easier the task of explicitly introducing the genre conventions, social practices, and linguistic features of scientific texts particularly important at the entry levels. Such explicit documentation can help teachers set assignments, provide relevant support, organize learning experiences, and assess following specific guidelines. Instruction that is self-conscious about its language practices can help direct students into the world of scientific thinking in a meaningful way.

The need for explicit experiences with science writing may arise even for students skilled in writing within literary or humanistic domains but not familiar with the special demands posed by science writing. As shown here these demands include creating multiple layers of assertions ('stacked facts' following Latour 1987) tied together with unifying concepts and developing ways of supporting claims with evidence. The claims further had to both be mutually supportive and tie together into a coherent argument.

The specialized form of argument needed for success in this assignment (and we can assume in assignments like it) requires that students become adept with making specific types of claims, linking those claims into specific forms of coherence, and tying both separate claims and the overall coherent argument to specific data obtained in methodologically appropriate and accurate ways. Making the structures of argument visible and explicit, as the analyses in this paper do, is a first step in providing consistent instruction, support, and assessment that may enable more students to achieve successful arguments more regularly. This is important since such successful arguments provide evidence that the students know how to think scientifically.

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APPENDIX

Mid-Term Paper Assignment

Due Date: See Syllabus.

Length: 6-8 pages. You can satisfy a UCSB writing requirement by writing 1,800 words, which is 6-8 pages. If you want this course to satisfy this requirement, make your paper at least 6 pages long (double-spaced, not counting figures).

Subject: Evidence for plate tectonics. You will access topography, volcanoes, and earthquake data from the "map" software. You will use your textbook and these data to study and write a technical paper about:

→ The most important global (world-wide) features that are the result of plate tectonics, and the active tectonic processes influencing the topography of:

a) one or more smaller areas from the "Area Maps" (you choose which area map most interests you),
b) the area map of the assigned small region. Build this work on your results from the homework (and discussions) of lab section #3.

- You will support all of your writings with geological/geophysical evidence from the "Map" software, in a technical paper format.
- It is not necessary for you to choose the small areas indicated on the map. If you want to study another region, discuss it with your TA or the professor.

Suggestions:

- Follow the hints and ideas given in the lab section #3 chapter. In this section, pay careful attention to "Questions that provide clues" so that you can apply your answers to the areas you are writing about.
- Pay careful attention to the Section #3 homework problem where you describe the assigned small area. This will help you make the best use of the ensuing discussions that will occur during your lab section. It will also give you a good start on your mid-term paper.
- Choose small areas that contrast each other so you can point out the differences between regions and how they illustrate these differences.
- Read the course text carefully so that you understand the properties of the 3 types of plate boundaries.
- Use maps and figures to illustrate your findings.

Format checklist:

- __ Name, section, and perm number at the top.
- __ All specified headings included (see "Format of Paper" below)
- __ The paper may include any number of figures and drawings. Small figures should be included in the text (drawing them on the computer is optional). Full page figures can be inserted at the closest spot where they are referred to.
- __ Double space the paper. Minimum words for writing credit = 1800.
- __ Do not include any figures xeroxed from the textbook.

⇨	Hand in your original paper, and a xeroxed copy. Credit will not be given without a copy.

Mid-term paper grading:

Your mid-term paper must follow the technical writing format described in previous sections. It will be graded on the following criteria (and according to the checklist at the end of each major heading)

- Format: Did it follow the technical writing format? Was written material put into the appropriate sections? Are all of the required sections included?
- Coverage: How well did you cover the important features? Did you miss something major? Did your paper reflect a knowledge of the theory of plate tectonics?
- Observations: Did you effectively describe your observations? How relevant were your observations to your interpretations? Were your observations quantitative? Did you make observations from the "our Dynamic Planet" CD-ROM?
- Interpretations: Did you use the observations (data) to support your interpretations? Were the interpretations clear?
- Figures: Were your figures neat and clear? How effectively did you use them to support your observations and interpretations? Did you refer to the figures in the text?

Figure 7: Writing prompt

NOTE

An earlier version of this paper entitled, 'How Students Argue Scientific Claims: A Rhetorical-Semantic Analysis,' was presented at the annual meeting of the American Education Research Association Seattle, WA 10–14 April 2001.

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