20 Rhetorical features of student science writing in introductory university oceanography

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Studies of science education have provided evidence for the importance of writing in students coming to understand and use scientific concepts (Keys, 1999; Rivard & Straw, 2000; Wallace, Hand, & Prain, 2004), as well as learning to participate in science as a learning community (Chinn & Hilgers, 1999). These findings are consistent with work over the last three decades in writing across the curriculum, focused both on writing to learn (Britton, Burgess, Martin, McLeod, & Rosen, 1975; Emig, 1977; Fulwiler & Young, 1986), and writing communities in the classroom (Walvoord & McCarthy, 1990; Herrington, 1985).

Simultaneously, studies in the rhetoric of science have made visible that writing and argument play important roles in scientists' and technologists' thinking and forming knowledge communities. The forms of expression, invention, and knowledge vary with professions and disciplines. The epistemic activity of researchers is saturated with 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, 1988; Blakeslee, 2001; Knorr-Cetina, 1999; Latour, 1987; Swales, 1998; van Nostrand, 1997). The representation and role of evidence in relation to generalizations and claims has been crucial in the development of scientific argument (Bazerman, 1988; Chandler, Davidson, & Harootunian, 1991; Fleck, 1979; Lynch & Woolgar, 1990).

This chapter brings together research in science education with research in science studies and in scientific writing to consider evidence formation in student writing.

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 through the reasoning displayed in texts open to criticism and evaluation. This perspective highlights scientists' need to refine reasoning, limit theoretical claims, marshal evidence, and understand 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).

To learn the argumentative practices of their fields, students must gain a feel for the communicative forms, forums, and dynamics of their fields. They must learn the kinds of claims people make and how they advance them; what literatures people rely on and how these literatures are invoked; what kind of evidence is needed to warrant arguments and how that evidence can be appropriately developed, analyzed, 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 develop their discipline-specific communicative skills, they enter into community practice of empirical investigation and application of communally developed knowledge. In this communal engagement with the material world (Goodwin, 1995) the role of evidence is centrally important. 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 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; Freedman & Medway, 1994; Swales, 1990; van Nostrand, 1997). Related analyses have looked at the rhetorical specifics and strategies of individual cases of argument (Bazerman, 1993; Pera & Shea, 1991).

This chapter brings this research to bear on how student writers make local linguistic, argumentative choices within a genre's organization and the expectations invoked within the activity system—here encapsulated in a school assignment that foregrounds the use of evidence in relation to claims.

While argumentation in spoken discourse has been examined extensively in science education (e.g., Erduran & Jimenez-Aleixandre, 2008; Sampson & Clark, 2008), writing provides a potentially useful strategy to engage students in the social and cognitive practices of evidence formation. Writing tasks can be constructed to socialize students to disciplinary knowledge, norms, and practices, providing realistic learning tasks, as in the case examined here. Written argument can also be used to assess students' engagement with scientific knowledge, norms, and practices.

Educational setting

The study was conducted in an introductory oceanography course at the University of California, Santa Barbara. The instructor (fourth author) of the course has been consulting for several years with the first two authors (Bazerman, Kelly) as part of his reflective development of this course and the related software. 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 is a subject that university students usually have little prior experience of in secondary school. Most of the 96 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 a scientist" 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, 2001, p. 2).

Writing was a key instructional component of this course. For the purposes of our analysis in this chapter, we examined the first paper that required students to engage in scientific practices 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. 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 (see Kelly, Regev, & Prothero, 2008; Prothero & Kelly, 2008).

The students attended three one-hour lectures, offered by the course professor, and one two-hour laboratory session of approximately 20 students each week, 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, including 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 magnifications, 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 asked students to formulate arguments characterizing plate boundaries and motion in terms of the theory of plate tectonics, based upon relevant data. The assignment included suggestions about the relationship of this assignment to previous work, uses of evidence for plate tectonics, and arguments based on geophysical evidence. 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 (see Kelly & Takao, 2002; Kelly, Chen, & Prothero, 2000).

Methods and results

To test the hypothesis of a pilot study of two papers (Kelly & Bazerman, 2003), we increased the number of student papers by using a random sample of 18 student papers from the total number of 96 students enrolled on the course during the 2001 version of the course. For each of the student papers we entered each sentence verbatim into an Excel™ spreadsheet from the seven pre-specified sections of the papers: abstract, introduction, methods, observations, interpretations, discussion, and conclusion. We then proceeded with the three initial analyses of the rhetorical, epistemic, and semantic cohesive dimensions.

Rhetorical dimension: Our first analysis considered the rhetorical tasks and subtasks of the technical paper as defined by the seven pre-specified sections of the papers. Our pilot study suggested that while there were rhetorical moves that could be identified within paper sections (following Swales, 1990, the theoretically salient differences occurred as students moved across the predefined sections from overview and introduction (abstract, introduction); to stating facts of the matter (methods and observations); to the more theoretically oriented arguments (interpretations, discussion, and conclusion). Two methodological issues surfaced. First, the "discussion" section was newly added to previous sections of the writing assignment and requested that students put their "findings into a broader context" (Prothero, 2001). This was the only section of the paper that was not described with "typical examples" and a "checklist" in the students' laboratory manual. The discussion sections thus introduced ambiguity into the analytical procedures. Second, two of the 18 students combined the interpretation and discussion sections with no clear demarcation. In these cases, we averaged numerical counts for the combined sections.

Epistemic dimension: Our second analysis consisted of identifying the level of generality of claim of each sentence. In those cases where compound sentences made claims at multiple levels we choose to code the sentence at the highest epistemic level. There were six epistemic levels, which represent a continuum from specific data-pointing claims (level I) to more general theoretical claims (level VI). An additional category "PC" refers to personal comment or other metadiscoursal remarks made by the author (e.g., "*Considering the plate tectonics that have taken place in the last 40 million years, it would be interesting to see what this region looks like in* *another 40 million years."*). 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 analytic levels are available in Kelly & Takao, 2002.)

Our analysis procedures consisted of developing initial common agreement among three coders of the respective definitions. The 18 papers were coded sentence by sentence by two coders (Kelly, Skukauskaite), differences discussed and brought to a third coder (Bazerman). All cases of disagreement were resolved through consistent principles that emerged in discussion. Table 20.1 shows the variation of the epistemic level of claim across the sections of the 18 papers as well as identifying the averages for the four highest- and lowest-rated papers. The highest level of epistemic claims (most theoretical) occurred in the conclusion, followed by the interpretations and discussion sections, the abstract and introduction, followed by the observations and methods (least theoretical, most factual).

Semantic cohesive dimension: A third analysis concerns ways the students' arguments cohere lexically, with particular attention to semantically related specifics and generalizations. Based on the work of Halliday and Hasan (1976) and Hoey (1983, 1991), our specific focus was on reiteration 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).

We treat synonymous terms (e.g., earthquake, tremor, seismic) as distinct lexical items. We also did not consider indexical pronominal references (e.g., "these" referring to specific earthquakes) as lexically cohesive with the original term. Within this corpus no lexical items had dual meanings, with all terms used univocally and explicitly. We have not, however, studied this interesting lexical univocality and how it might be related to the technicality of the writing task or the state of student knowledge. Nonetheless, the convergence of semantic meanings and lexical forms in this case simplifies the analysis.

After identifying the specific lexical cohesions in each sentence, we then sought to examine the overall cohesive picture of each student paper through four analyses. First, we plotted the key terms (those identified as having at least one repetition) by first mention (y-axis) against the sentence sequence (x-axis), noting the placement of these terms in the sentences comprising the paper (see Figure 20.1). For example, for the student paper mapped in Figure 20.1, the term "plate" appeared in the following

Table 20.1. Aggregate distribution of epistemic level of claims across paper sections. Shown are the results for the total number of student papers (n = 18) and then the subset of 4 highest and lowest rated papers by subject matter expert

Paper sections	*Average epistemic level of claim*					
	Total sample (n = 18)		*Highly rated papers (n = 4)*		*Lowest rated papers (n = 4)*	
	average	*stdev*	*average*	*stdev*	*average*	*stdev*
Abstract	3.88	1.22	3.91	0.32	3.86	0.59
Introduction	3.55	1.76	4.16	1.57	4.42	0.89
Methods	1.20	0.56	1.17	0.19	1.08	0.17
Observations	2.59	1.02	2.52	0.48	2.99	0.53
Interpretations	4.07	1.07	3.91	0.39	3.94	0.27
Discussion	4.03	1.43	4.83	1.08	4.39	0.63
Conclusions	4.23	0.97	4.00	0.38	4.63	0.48

paper sections:	abstract					introduction					method								observations										interpretations																discussion									conclusion					
term\ Prop #	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	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	56	57	58	59
plate	1	2		4	5	6		8	9																				29	30	31							38	39	40	41	42		44	45	46	47	48						54			57	58	59
plate tectonic	1					6																																							45														
tectonic	1					6																																							45														
Fiji	1					6	7	8											19	20								28				32													45						51			54			57		59
eviden-		2						8													21									30		32			35																				55				
trench		2																				22		24		26	27	28	29	30	31						37			40											51				55				
rise		2																				22		24						30	31																												
earthquake		2	3					8									17	18							25	26			29								37			40															55		57		
volcan-		2						8							15	16		18										28	29			32	33	34	35	36															51				55	56			
island-		2					7	8															23						29			32	33	34																					55	56			
converg-		2																													31				35												47							54					
margin		2																																	35																								
convergent plate		2																													31																												
depth			3																					24			27										37			40																	57		
pattern			3																								27										37			40																	57		
depth pattern			3																								27										37			40																			
subduct-			3	4																															35	36	37	38	39	40											51			54		56	57		
zone			3	4																															35	36	37														51			54		56			
subduction zone			3	4																															35	36	37														51			54		56			
subduction zone			3	4																															35	36	37														51			54		56			
direction				4																																						42		44		46													59
Pacific					5																																		39	40		42				46											57	58	
Pacific plate					5																																		39	40		42				46											57	58	
north					5																	22		24		26	27													40		42				46											57	58	59
west					5																																					42				46												58	59
northwest					5																																					42				46												58	
Indo-Australian					5																																		39	40		42				46											57	58	
mov-					5				9																																	42		44	45	46	47	48										58	59
east					5																	22				26																42				46											57	58	59
fig.=figure						6															21		23	24	25		27	28		30						36	37																						
activ-							7												19													32	33																							56			
area							7		9	10									19	20			23		25		27	28	29				33							40	41				45									54					
sea								8								16						22																												50									
floor								8						14								22																												50	51								
sea floor								8														22																												50									
data								8		10	11	12		14	15		17	18																														48		50									
boundar-								8																						30	31										41															59			
plate boundar-								8																						30	31										41															59			
topograph-												12									21	22							29																														
dataset												12					17	18																																									
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land																16																																			51								
locat-																	17			20																																							
profile																		18					23																																				
surround-																			19																										45														
Tonga trench																						22	23				27										37																						
south																						22				26																															57		
southeast																						22				26																															57		
deep																							23																																55				
line																										26		28															43																
theor-																																				36												48											
idea																																												44					49	50									59

Figure 20.1 Sentence-by-sentence analysis of lexical cohesion for highest-ranked paper.

sentences: 1, 2, 4, 5, 6, 8, 9, 29, 30, 31, 38, 39, 40, 41, 44, 45, 46, 47, 48, 54, 57, 58, and 59. By considering these key terms, their introduction, their place in the overall organization of the paper (in sections, place within and across sections) and their frequency, we were able to get an overview of the text organization. For example, our subsequent cohesion analyses (cohesive terms per sentence, examining key-term use, and section boundary sentences) followed from the cohesion plots like that of Figure 20.1.

Our second analysis considered the average number of cohesive terms per sentence, aggregated by paper section. We were interested in examining how the differing rhetorical needs of the paper sections led to variations in lexical cohesion. As shown in Table 20.2, we considered the entire sample as well as the four highest- and lowest-rated papers.

Third, we were interested in examining how the cohesion exhibited by first sentence of a paper section compared to the overall cohesion within the specific section. For example, consider sentence 29 in Figure 20.1, which in its original form read: *"The topography of the area has resulted from the shifting of the plates which has caused the abundant earthquakes and volcanoes, as well as the trenches and the islands."* Through the analysis presented in Figure 20.1, this first sentence of the interpretations section can be seen to be bringing together a theoretical term (*plates*) and geological features (*trenches* and *islands*) with data-referencing terms (*area* and *topography*) and specific data items (*earthquakes* and *volcanoes*.) To examine this in detail we considered the number of cohesive terms per sentence for the first sentences of each paper section and compared these values with the overall number of cohesive terms per sentence for the relevant section. A summary of these calculations in presented in Table 20.3.

Our fourth consideration of lexical cohesion concerned use of some of the terms across the 18 student papers. From the initial lexical cohesion maps (Figure 20.1) we considered those terms used by the most number of students. Of the terms appearing most often by the student writers, 12 can be classified into four categories: (a) theory terms (plate, subduct-, converg-) refer to words that cannot be read off the data representations and require some understanding of the mechanisms of plate tectonic theory; (b) data terms (volcan-, ocean[ic], [earth]quake) refer to words that can be viewed as icons in the data representations of the CD-ROM database; (c) terms referencing data representations (data, profile(s), figures(s)) locate data and draw readers' attention to data; (d) directional terms are south, north, west, east, and combinations such as northwest, etc. For these four types of terms we were concerned with the number of students making use of the terms and in which sections they appear. Our focus was on appearance, and not the total number of times a term occurred. Figures 20.2a–d represent the different ways these four types of terms were used by the student writers across the paper sections.

Table 20.2 Average number of cohesive terms per sentence in each paper across sections (n = 18)

Paper sections	*Average number of cohesive terms per sentence*					
	Total sample (n = 18)		*Highly rated papers (n = 4)*		*Lowest rated papers (n = 4)*	
	average	*stdev*	*average*	*stdev*	*average*	*stdev*
Abstract	8.75	1.55	8.26	2.01	8.91	2.09
Introduction	7.49	2.16	7.75	1.96	6.55	2.20
Methods	4.59	2.19	3.88	1.49	4.91	2.60
Observations	6.43	1.33	6.43	0.81	6.55	1.49
Interpretations	7.20	1.67	6.41	0.89	7.18	1.80
Discussion	5.70	1.55	5.29	1.08	5.25	2.37
Conclusion	8.75	2.59	7.58	0.79	9.08	3.85

Table 20.3 Comparison of cohesive terms used in first sentence in paper sections with total in respective sections

Paper sections	*Comparison of first sentence of paper sections with total section average number of cohesions*	
	First sentence higher number of cohesive terms	*First sentence lower number of cohesive terms*
Abstract	8	10
Introduction	9	9
Methods	7	11
Observations	11	7
Interpretations	13	5
Discussion	11	5
Conclusion	11	7

Discussion of hypotheses in light of results

The previous study of two highly rated papers suggested five hypotheses which we tested against this larger, more varied sample.

Hypothesis 1: The arguments showed a hierarchical arrangement within the logic of the genre structure, i.e., the students introduced and maintained use of key conceptual terms (e.g., plate, tecton-, topograh-, boundary(ies)). 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).

Hypothesis 2: 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.

Our first and second hypotheses are closely related. They both examine the relationship between epistemic level and organizational components of the paper arguments. As in the original study we found distinctive differences in epistemic level among the predefined sections of the paper (abstract, introduction, methods, observations, interpretations, discussion, conclusion), and these differences followed the organizational logic of the different sections. These differences followed a high–low–high pattern (see Table 20.1) as in the original study, with abstract and introduction presenting material of a higher epistemic order (3.88 and 3.55 on a six-point scale, respectively) than the methods and observations (1.20 and 2.59, respectively). Then the interpretations, discussion, and conclusion include claims of higher epistemic level and thus theoretical import (4.07. 4.03, and 4.23, respectively). Further within the middle section, observations exhibited higher epistemic levels than the methods.

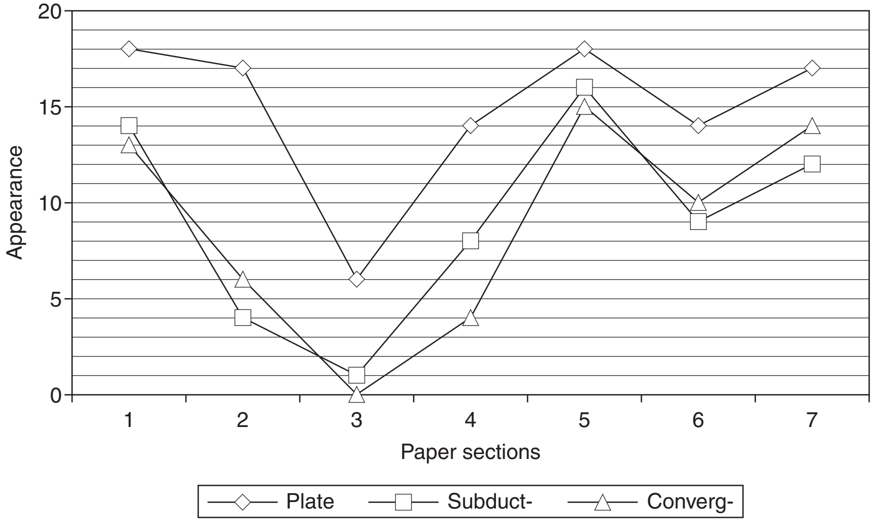

Figure 20. 2a Appearances* of theory terms across paper sections.**

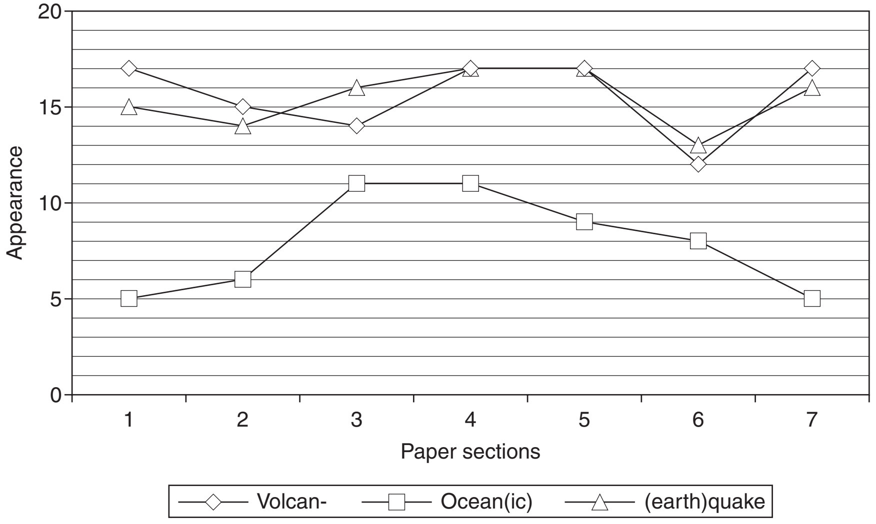

Figure 20.2b Appearances of the data terms across paper sections.

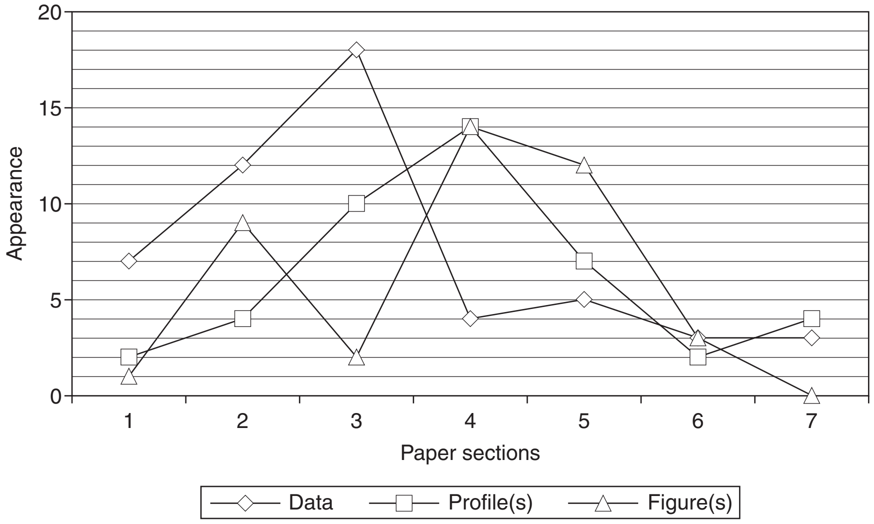

Figure 20.2c Appearances of data referencing terms across paper sections.

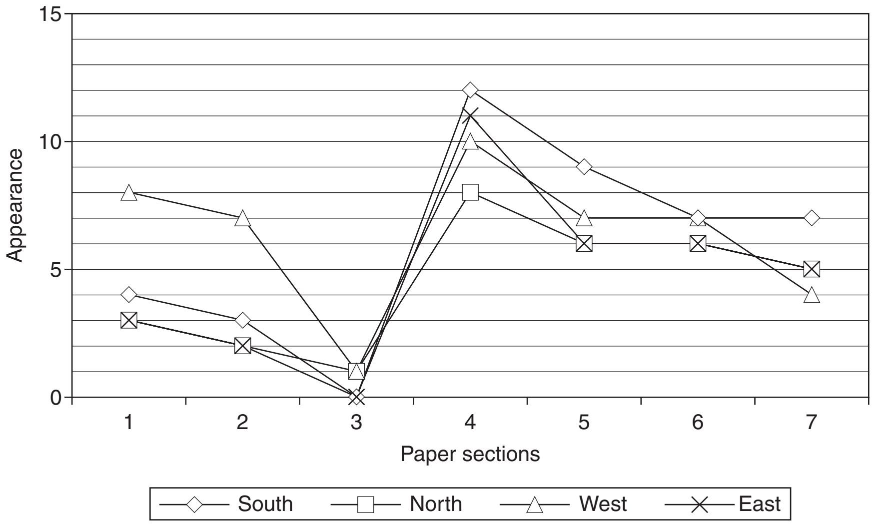

Figure 20.2d Appearances of directional terms across paper sections.

Notes
*"Appearances" refer to number of students using term in respective paper sections.
**Paper sections are as follows: 1 = abstract, 2 = introduction, 3 = method, 4 = observation, 5 = interpretation, 6 = discussion, 7 = conclusion.

Hypothesis 3: 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 in the earlier study 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. The aggregate results (see Table 20.2) of the analyses of the repeating terms in each paper reflect the same pattern of higher cohesiveness in the first two sections and the interpretation and conclusions. The methods and observations section had on aggregate fewer cohesive terms per sentence. The added and less well-defined discussion section did not conform so clearly to this pattern.

Hypothesis 4: 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.

Our fourth initial hypothesis concerning the greater cohesiveness of boundary sentences was not confirmed in a direct form. However, the sample of 18 papers exhibited a more complex pattern. When examining the first sentence of each section we found different patterns in the different sections. In the first two sections (abstract and introduction) the introduction sentences did not differ from the cohesive pattern of the sentences in the whole section. This was measured by seeing whether the introductory sentence had more or fewer cohesive terms than the average of all sentences in that section. The third section (methods), however, reversed our expectation by having more introductory sentences with fewer cohesive terms than the section averages (11 lower, 7 higher). The final four sections, nonetheless, followed our original expectations, with the first sentence of each section having more cohesive terms than the sentences that follow. As shown in Table 20.3, for at least 11 of the 18 cases in each of the four sections, the lead sentence had more cohesive terms than the average number of cohesive terms per sentence in the section. This pattern echoes, in some respects, the pattern of epistemic levels and cohesive density revealed in the results of our tests of the first two hypotheses.

Hypothesis 5: Often repeated terms built up cohesive density and thematic saliency as they were associated with other terms in different sections of the paper.

In exploration of our fifth hypothesis we identified the terms that were used by the most student authors. Among the most prevalent terms, appearing in almost every paper, we identified four categories of words: terms referring to theoretical concepts (plate, subduct-[ing, ion], converg-

[ing, ence, ent]); terms referring to specific geologic formations directly reported in data (volcan-[o, ic], ocean (oceanic), (earth)quake); terms referring to aggregations of data (data, profile[s], fig[ures]); and terms of direction (south-, north-, -west, -east). When we analyzed the appearance of these terms across each of the sections of all 18 papers, distinctive patterns of distribution emerged for the different kinds of terms (see Figures 20.2a–d).

The theoretical terms (see Figure 20.2a) consistently appeared in the first and last three sections. Although there was variation in sections 2–4, each had the fewest appearances in the methods section. The variation may be due to the difference in character among the terms with plate being part of name of the overarching theory (plate tectonics), with the other two terms describing processes identified by the theory. The data terms appeared consistently across all sections (Figure 20.2b), but the terms indicating aggregations of data were less prevalent in the first and last two sections. Terms making reference to data appeared most frequently in the methods and observations sections, although the terms considered showed significant variation in patterns of use (Figure 20.2c). The directional terms have the highest appearance in the observations section, and continue with comparatively high appearances throughout the last three sections (Figure 20.2d).

In order to determine if the patterns we observed were consistent across the range of papers, we compared the epistemic and cohesive profiles of the four papers judged of highest quality by the course professor with the four papers rated lowest. We found that both groups fit the pattern equally well (Tables 20.1 and 20.2). Specifically, the average epistemic level of the statements in each section of the four highest and four lowest papers fit the epistemic pattern noted across all papers with roughly equivalent values, well within the standard deviation of the averages of all papers (Table 20.1). Further the average number of cohesive terms per sentence in each section in the four highest papers and the four lowest papers conformed to the general shape and values of all 18 papers, well within the standard deviation of the overall numbers (Table 20.2). We did not pursue for the high and low papers our other two measures (of first sentence cohesion and key-term appearance) because our method of analysis by appearance in each section did not lead to sufficient number of instances to produce meaningful results. Thus it appears that in this class for this assignment, students of both high and low achievement had sufficient genre knowledge of the assigned paper to produce sentences of the epistemic level and degree of cohesion appropriate to each section. The more theoretical sections of both high and low papers showed a higher epistemic level for claims and more cohesive terms per sentence than the methods and observations sections.

General discussion

All hypotheses and results reveal the same assignment-appropriate pattern of organization of argument, which we may characterize as the Epistemic U. Specifically the epistemic levels, the degree of cohesion, the cohesiveness of introductory sentences in the later sections, and the appearance of different kinds of repeated terms within the sections of the paper all conform to a single pattern consistent with the following arrangement of the sections of the paper: The overview and introduction present the material to be discussed at a higher theoretical level. The methodological section is more concrete. The observation section begins to report the data in patterned ways that reaches back up toward theory, and the final sections consider the reported data in theoretical terms.

Greater theoretical orientation is associated not only with epistemic level, but degree of cohesion, the use of theoretical terms, and in the later sections, use of aggregating statements at the beginning of each section. These language patterns work together to structure the exposition of data in relation to the development of concepts. This rhetorical knowledge is apparently shared by all students sampled.

From applied linguistic and rhetorical perspectives, such evidence of section by section structuring of several different kinds of features of language (level of claim, cohesiveness, use of aggregating introductory sentence, and use of particular kinds of lexical terms), points toward how aspects of language form are organized within genres.

From the point of view of research in science education, our findings raise questions about how the students came to learn the genre conventions, whether such knowledge contributes to competence in the disciplinary domain, and whether there are other knowledges required for further participation and success in the relevant social-rhetorical practices.

The first question regarding how all students came to know and use the same genre knowledge with respect to epistemic levels and cohesion in this case appears to result from explicit instruction in the genre organization and epistemic levels of the paper. As a result of the findings of Kelly and Takao (based on the 1998 iteration of the course) and related investigations and consultations, the instructor added explicit instruction in the laboratory manual concerning epistemic level of claim and provided examples of poorly written and well-written student papers in this regard. Students in the 2001 version of the course studied here were given exercises to assess the epistemic level of each claim in weaker and stronger sample papers (Takao, Prothero, & Kelly, 2002). This material was reinforced in lecture and laboratory section with the teaching assistants. While there was some discussion of developing coherent arguments and using appropriate vocabulary consistently, there was not explicit instruction of lexical cohesion, nor was that term introduced. The patterns of cohesion and terminological appearance may then be to a greater or lesser extent cognitive and/or formal consequences of the scaffold established by the assigned and instructed form.

The implication would be that students learn what they are taught, but this still leaves open the question if what they were taught was significant and sufficient to lead students to scientific reasoning. The question remains whether instruction in the genre leads students to produce substantive reasoning or merely empty formalisms? If it is of value, are there other crucial elements of the genre to be taught? And what other reasoning skills that are not implicit in the genre also need to be taught? The significance of the genre knowledge for reasoning may be assessed by investigating the relationship between this knowledge and other measures of scientific reasoning. Such a measurement of scientific reasoning would have to be sensitive to the task-specific features of the student writing, which include familiarity and facility with the relevant geologic theory. Furthermore, if, as we argue in this chapter, scientific reasoning is associated with the form of the argument through which it is realized, it is hard to disambiguate tests of reasoning from genre knowledge.

Conclusion

The arguments presented in student responses to the assignment studied uniformly exhibit a clear epistemic and cohesive structure that corresponds to the sections of the assigned paper. This public display of structured reasoning through students' written work provides an important means of knowing how students reason scientifically in a specific subject and problem context. Further, analysis of assigned writing is a non-obtrusive and ecologically valid procedure, which builds upon the already existing concerted activity of the members of the classroom. Researching scientific reasoning in this way allows for recursive change in the instruction, since a major goal of instruction is the successful production of reasoned argument in the form of these assigned papers. In the case of this study, the recursive effect is further facilitated by the inclusion of the instructor in the research team. Increased knowledge of the form and substance of successful argument holds the promise of improving reasoning with scientific evidence and concepts through more informed instruction.

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