Chapter 7
Analysis of Lines of Reasoning in Written Argumentation

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Written texts play an important role in the activity systems generating knowledge in professional and educational settings. Empirical studies of the social construction of scientific knowledge in scientific and school settings have identified a range of purposes, uses, and genres of written communication (Kelly & Chen, 1999; Knorr-Cetina, 1999). The persuasive discourse of written argument is one such type of written communication that has played a significant role in the development of scientific knowledge (Bazerman, 1988; Gross, 1990). As noted by Yore et al. (2006), written communication provides a means to articulate evidence, warrants, and claims; reflect on proposed ideas; critique the scientific work of others; and establish proprietorship of intellectual property. An important dimension of science learning is the ability to use, assess, and critique evidence (Hodson, 2003; Yore et al., 2003). This ability includes understanding the relationships among questions, data, and claims, as well as how these relationships can be organized to formulate evidence for a given task and audience (Wallace et al., 2004). While the use of evidence in reasoning is a noted goal of scientific inquiry, little research has focused on the difficulties students may have integrating data with text to formulate coherent arguments. This chapter examines specific rhetorical demands necessary to prepare a successful scientific argument. The theoretical framework for this study incorporates research of writing to learn science and argumentation in science. We investigate these issues in a technology-rich university oceanography course designed for undergraduate non-science majors.

The objective of this chapter is to identify and analyze the nature of the claims being made by the student writers and how these claims are developed as the lines of reasoning supporting a thesis. These analyses illustrate ways that large-scale earth data-sets can be used to prepare students to examine and employ evidence in scientific and socio-scientific domains. Drawing from the fields of argumentation theory and rhetoric of science as well as previous studies of an ongoing research program, specific epistemic and rhetorical criteria are developed and applied for the purposes of assessing the strength of the students' arguments. These criteria were brought to bear on two types of writing tasks with differing rhetorical demands. In one case, the students use geological data to develop and sustain theoretical arguments regarding plate tectonics. In a second application, the students consider broader earth-climate issues, using similar evidence-based argumentation practices,

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yet with less specific task requirements. Through application of the epistemic and rhetorical criteria, we identify ways that scientific argumentation can be analyzed with respect to individual student writers. We discuss implications for uses of argumentation in science instruction, particularly as related to socio-scientific issues.

Argument in Science and Schools

An emerging literature in science education dedicated to the application of argumentation to educational processes has identified the importance of students' learning how to use, evaluate, and critique evidence. Broadly speaking, argumentation refers to the ways that evidence is used to persuade a reasonable critic of the merits or lack thereof of a standpoint or position (van Eemeren & Grootendorst, 2003). Analytic tools are emerging to consider how to assess students' uses of evidence in the context of science inquiry. This literature identifies a need for creating discipline-specific, ecologically valid measures of the strength of students' arguments given the specific task constraints (Erduran et al., 2004; Kelly & Takao, 2002, Sandoval & Millwood, 2005; Takao & Kelly, 2003). Furthermore, how students reason about socio-scientific issues has been shown to be tied to issues of evidence use, the nature of science, and students' conceptual understanding (Sadler, 2004).

While most studies of student argumentation have focused on spoken discourse (Driver et al., 2000; Jiménez-Aleixandre et al., 2000; Sadler, 2004) written argument poses unique possibilities and challenges for science education (Rivard & Straw, 2000; Wallace et al., 2004). Some unique opportunities of writing in science are as follows. First, writing offers the possibility of creating author-generated and publicly available texts that can serve as a basis for personal reflection, intersubjective scrutiny, and multiple revisions. Students may learn science from writing the papers, reading those of others, and offering formal reviews of other students' work. Second, writing brings arguments to closure and allows the rhetorical aspects to stand the test of evaluation over time. The evolution of an author's position allows the author and readers to learn from the emerging evidence embedded in the text. Third, writing provides a potentially useful strategy to engage students in the social and cognitive practices of evidence formation (Kelly & Bazerman, 2003). Writing tasks can be constructed using the disciplinary resources of data and investigative tools to acculturate students into disciplinary knowledge, norms, and practices.

Written argument also poses pedagogical challenges. First, the development of written argument requires many general as well as task-specific language skills (Kelly & Bazerman, 2003). 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 & 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) (Halliday & Martin, 1993; Kelly & Green, 1998; Myers, 1990). Because of the diversity of science and writing, student writing needs to be sensitive to task-specific features of the local educational and disciplinary contexts (Kelly & Bazerman, 2003).

Second, written argument in science entails persuading a critical community of peers. The persuasive use of evidence poses challenges for science writers. Rhetorical studies of science have identified the importance of the ways that knowledge claims (and authors of such claims) are held accountable to public standards (Bazerman, 1988; Gross, 1990). Forwarding knowledge claims in a persuasive form often entails recognizing ways to make evidence clear to the audience, limiting the theoretical import of such claims, using citations to build intellectual and epistemic alliances, and making claims credible to critical communities of peers (Latour, 1987; Myers, 1990; Pinch, 1986). Formulating evidence in such a manner requires that the author recognize those aspects of persuasion that are situationally specific as well as those that are constrained by the norms of the genre conventions (Gieryn, 1999). To write in this way, students need to have command of the key concepts of a field, understand features of the specific genre, and recognize the level of detail required to make a persuasive case (Kelly et al., 2000).

Third, engaging in scientific inquiry involves participating in a community with the common sociocultural practices (Kelly & Green, 1998; Wenger, 1998). In this case, students need to develop their individual communicative skills in the context of collective activity. Such activities often include specific ways of observing, inferring, referencing, speaking and so forth, and are increasingly directed around inscription devices and other technologies. Thus, cognition is distributed in space and time; applying knowledge involves becoming a member of a group and being part of a communal engagement with the material world (Goodwin, 1995). To the extent that educational processes seek to reproduce some aspects of science, this communal engagement entails high levels of accountability between detailed findings and general idea claims, particularly as applied to uses of argument in the written form (Bazerman, 1988; Kelly & Bazerman, 2003; Myers, 1990).

Studies of Written Argumentation in University Oceanography

The study presented in this paper builds on work over the past 10 years in which cycles of research, development, and application have been conducted between course developer and programmer, William Prothero (third author), and an evolving educational research team, led by Greg Kelly (first author). The cycle includes studies of the framing of the earth science knowledge and writing characteristics (Kelly et al., 2000), of students' uses of evidence (Kelly & Bazerman, 2003; Kelly & Takao, 2002; Takao & Kelly, 2003), and applications to changes in pedagogy (Takao et al., 2002). The educational research has sought to demystify the knowledge and practices entailed in writing scientific arguments and to contribute to a series of tools aimed at mediating the knowledge and practices.

As the current study builds on previous cycles of research, development, and application, we provide a brief review of previous results. An early study examined the framing of oceanography through instruction by the course professor, teaching assistants, and associated tools for writing (Kelly et al., 2000). This study identified ways teachers and students served as social mediators of the relevant disciplinary knowledge through the everyday practices associated with teaching and learning oceanography. Specifically, two thematic stances toward scientific writing emerged in the course. First, 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. Situating writing in a broader context identified the contextual values (Longino, 1990) of the discipline of oceanography, as articulated in this case. Second, writing in science was presented as being shaped by a community's procedures, practices, and norms. These procedures, practices, and norms are internal to the workings of science, and are thus identified as constitutive values (Longino, 1990). Such internal constitutive values related to writing include expectations about uses of data, standards for evidence, uses of references, and form, sequence, and structure of the text and other genre conventions. 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 tool to assess the university oceanography students' use of evidence in writing (Kelly & 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 analyze the relative epistemic status of propositions in students' written texts. The model is shown in Fig. 7.1

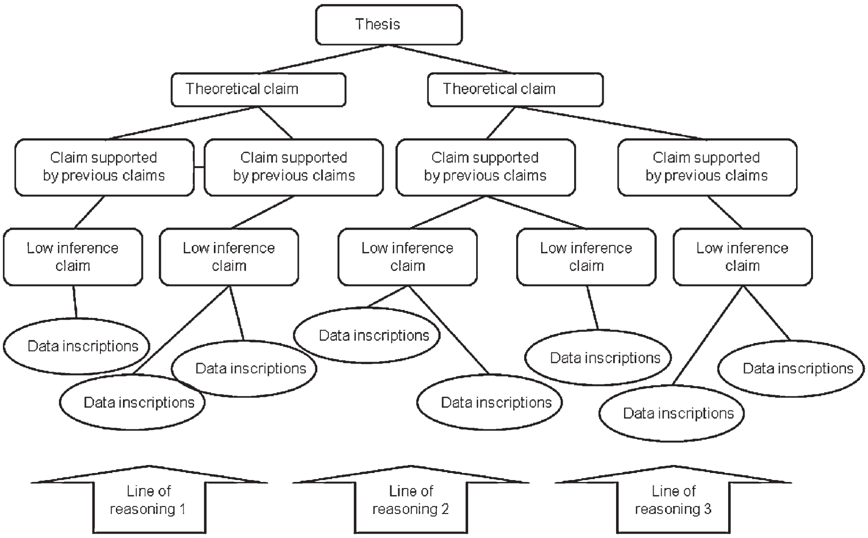

Fig. 7.1 Schematic of argument structure and assessment criteria

and described in detail in a subsequent section of this chapter. The argumentation model introduced identified a disciplinary-specific progression of epistemic level of claims. 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 analyzed. 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 were 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 interviews 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 (2003) found that while all three populations were able to recognize distinct differences between the two papers, 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.

The fourth study (Kelly & Bazerman, 2003) developed analytical procedures to make explicit how features of written argument are signalled through linguistic cues. In this study two papers (chosen as high quality by the instructor—Prothero, third author) were analyzed in great detail. Five key features of argumentation as represented in this genre were identified. First, 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, combining these terms with specific geographical terms over the course of the varied rhetorical demands of the extended argument). Second, analysis of lexical cohesions revealed multiple cohesive links across the majority of the sentences forming the complete argument set in the technical paper. Third, 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. Fourth, the epistemic status of the claims made varied according to the rhetorical needs of the differing sections, defined by the genre structure. For example, the introduction, interpretations, and conclusions showed the greatest levels of generality, while the description of methods and observations were most specific. Fifth, often repeated (theoretical) terms built up cohesive density and thematic saliency, as they were associated with other (data-orientated) terms in different sections of the paper. For example, theoretical terms were introduced early in the arguments, were made relevant through their application in reference to the interpretation of specific data inscriptions.

Key Features of Geological Argumentation

The model for our argumentation analysis has been constructed through a series of theoretical and empirical investigations. Our model began originally with an application of Toulmin's (1958) layout of arguments (Kelly et al., 1998). While this layout of argument makes visible the importance of the theoretical backdrop supporting a move from data to a claim, the application of Toulmin's model to spoken and written discourse has typically been found insufficient to capture the complexity of dialogic reasoning (Erduran, this book; Erduran et al., 2004; Jiménez-Aleixandre et al., 2000). Most notably for the purposes of this chapter is that the oceanography students studied here are not attempting to make a single move from data to a claim. Rather, through a series of claims about varied data sources they attempt to build a complex argumentation structure. Therefore, the model was extended to include a consideration of the various epistemic levels of claims (i.e., degree of abstractness of knowledge claims) (Kelly & Chen, 1999; Latour, 1987; Myers, 1990) and more particularly the epistemic level of claim specific to the disciplinary context of the argument (Kelly & Takao, 2002; Takao & Kelly, 2003). Furthermore, geological reasoning requires developing independent, converging lines of inquiry (Ault, 1998).

A schematic of the model is presented in Fig. 7.1. This model distributes out students' statements into a set of lines of reasoning (beginning at the bottom) based on reference to empirical data and into epistemic levels—from grounded, low inference claims to claims with progressively more theoretical import. The model has proved some usefulness for 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 have been raised by the authors of the model (Kelly & Bazerman, 2003; Kelly & Takao, 2002) and others working on similar argumentative fields of science writing in schools (Sandoval & Millwood, 2005). Two concerns relevant to the current study are the ways that the substantive knowledge of the argument is assessed in terms of the *inferential reasoning* of the writers (based on a normative point of view) and how *rhetorical features* of the arguments serve to shape the evidentiary substance of the overall argument. These issues are particularly difficult given the range of topics of the student arguments and the even larger possible data sources.

These concerns regarding the formulation of argument are addressed in the following manner. We consider two epistemic criteria regarding the thesis statement (solvability, support) and three epistemic criteria regarding the lines of reasoning developed by the students (convergence, sufficiency, and validity). Based on previous work (Kelly & Bazerman, 2003; Takao & Kelly, 2003), we were able to identify some of the rhetorical features of the student arguments valued by the disciplinary experts (coherence, coordination, progressive construction). These features, described below, served as the basis for the current analysis.

Students need to pose a *solvable research question, or thesis statement*. Finding out what can be answered with the available data becomes an early hurdle for formulating a strong argument. The thesis statement must be clear, of manageable scope, and be potentially supportable by evidence. For the cases studied, multiple lines of reasoning are needed to make the case persuasively. For example, for students to claim that a subduction zone exists at some geographical area they may develop lines of reasoning around topology, earthquake locations and depths, and volcano locations. Three additional epistemic criteria can be brought to bear on the assessment of the thesis.

The *lines of reasoning need to converge* in a manner that is supportive of the thesis. As the writers are marshalling more than one type of data, these data sources need to each provide some evidence to the overall argument. The argument needs to be structured with interdependence such that the lines of reasoning are mutually supportive.

The *lines of reasoning need to be sufficient*, given the scope of the thesis. The academic tasks (described subsequently in detail in "educational context") required students to make complex arguments regarding the theory of plate tectonics and the earth's climate. The nature of the tasks required that the lines of reasoning developed show that they have enough evidence to support the thesis against alternative interpretations.

The *lines of reasoning need to be constructed with valid inferences*. This criterion may seem the most obvious. However, our previous studies noted that the validity of a student's line of reasoning was not easily unpacked by varied readers (Takao & Kelly, 2003). The question of validity, like convergence and sufficiency, is highly audience-dependent. In the given tasks, the students were not only required to state true statements about the given geographical areas, rather they were required to make a sound argument that provided evidence for a true statement about the chosen area.

Finally, there is a global question about whether the central thesis has been supported by the evidence provided. The problem for the writers was deciding how to marshal evidence, not state conclusions. Nevertheless, a strong argument makes a persuadable case that the *thesis is supported* by the evidence marshaled.

In addition to these five epistemic criteria, there are three rhetorical criteria for developing a sound argument. First, the student writers need to develop a *progressive construction of evidence*. The students need to build to larger claims through progressive articulation of smaller-level, lower inference claims. This is shown schematically on Fig. 7.1 as the ties across the epistemic levels of claims (shown on the vertical dimension). This progressive construction of evidence entails learning what sorts of inferences can be made about particular inscriptions, and then how low inference claims can be brought together to support more theoretical claims. The analysis of students' progressive construction of argument across epistemic levels is examined in studies by Kelly & Takao (2002; Takao & Kelly, 2003).

Second, the student writers need to develop *coherence across and within lines of reasoning*. Coherence is ultimately a matter of readers' construction of meaning (Kelly & Bazerman, 2003). Nevertheless, this meaning is likely cued through subtle textual hints. Assessing coherence may be aided by several formal linguistic techniques of cohesion (Halliday & Hasan, 1976). Our previous studies have identified cues such as indexical references (e.g., "this"), substitutions (e.g., pronouns), and lexical cohesion, specifically use of reiteration—the repeating use of the same word or word root (e.g., volcano, volcanic)—and collocation—the association of lexical items that regularly co-occur (e.g., plate and tectonic) (Kelly & Bazerman, 2003). The ties across claims, shown schematically in Fig. 7.1 as links, represent cohesion.

Third, the student writers need to *coordinate evidence across epistemic levels* that make explicit how particular inscriptions or claims provide evidence for higher order, more generalized claims. This concerns how well the students are able to draw data into explicit arguments. This involves making claims at multiple layers of epistemic generality (i.e., *progressive construction of evidence*), but doing so in ways that draw on data identified previously showing relevance for subsequent explanatory arguments. The progressive construction feature is represented in Fig. 7.1 as the coherent links that "trace" the lines of reasoning from data to thesis.

Educational Context

We now turn to research for this chapter drawn from a course taught at a large research university in southern California that integrates science, technology, and writing toward the goal of developing a scientifically literate citizenry. The course included from 80 to 120 students each quarter of the academic year, and satisfied both the general education quantitative science requirement and the university general education writing requirement. Students attended three hours of lecture and three hours of lab each week.

Several content themes were treated in this oceanography course including ocean basins, plate tectonics, earth's atmosphere, oceans and world climate, waves and beaches, and world fisheries. Course activities were organized about these topics. For each topic, students worked in groups to view the scientific and socio-scientific issues from the perspective of a specific country. The final culminating activity was a mock Earth Summit. As a member of the Earth Summit, students joined a "Country Group" and took on the role of a science advisor who was requested to present the point of view of their country as it related to the course themes of geological hazards and changes in the earth's climate. Throughout the course, all writing and in-class presentations were done from the perspective of the chosen country. Through a process of exploring real earth data sets, students identified major science issues related to their country. Students were required to gather relevant data, write scientific position papers, and discuss and present their findings to their peers. In order to successfully complete the inquiry assignments students needed to form an understanding of their country's unique perspective in the Earth Summit. There were indications that using the Earth Summit metaphor to guide oceanography instruction provides a context that stimulated student interest. Specifically, in-class presentations encouraged discussion of how point of view affects policy based on scientific relevance. Thus, through the dialogue the global consequences of local and regional policies were illustrated.

The overall educational aim of this course is to increase science literacy among the general student population. This aim is operationalized through goals that include developing relevant understanding of scientific phenomenon, analyzing scientific claims made in the media, and developing an awareness and appreciation of the dynamic interplay between science and society. Specific strategies have been designed that model classroom activities after those of practicing scientists, policy analysts, and citizens. Developing student writers of science required instruction and tools specifically designed to scaffold written arguments. These social and symbolic mediators served to initiate students into the particular epistemic practices valued by the instructor (Kelly et al., 2000). Epistemic practices are the specific ways members of a community propose, justify, evaluate, and legitimize knowledge claims within a disciplinary framework (Kelly, 2005). The series of activities and experiences have been designed to support the writing and inquiry tasks. We briefly describe these mediating social practices and artifacts (Kelly, 2005; Kozulin, 2003) to document the learning opportunities afforded by the educational experience.

Specifically, the writing assignments were supported by weekly online assignments including homework, multiple choice quizzes, thought questions, mini-studies, class presentations during lab, and small group discussions. For example, prior to attending lecture, students were expected to access the online server, complete the assigned reading, and answer short thought questions that required the students to demonstrate their understanding of the topics to be discussed in class. These thought questions were evaluated by the course professor and the teaching assistant and allowed the instructors to assess student understanding. Additional opportunities to guide students' understanding of the course themes occurred during lecture when students answer short questions of the day at the beginning of class. These questions gave students the opportunity to engage with course material, discuss their questions with peers, and promote dialogue between themselves and the professor. In addition to the independent work that students completed from home or in class, students were also given opportunities to work collaboratively by completing group investigations and group presentations in lab section meeting. This ongoing flow between independent and collaborative work provided the opportunity to support the investigations required of each student.

Consistent with the goal of developing students' abilities to use, assess, and critique evidence, the course professor provided detailed instruction and a series of mediating artifacts to support the work of writing the two required scientific papers.

These supports, which were available in the course reader, on the course website, and again on the online writer, provided students with an outline of the format for the technical paper, including descriptions and examples of each section of the paper. Additional texts were available to students in the course reader and at a course website that detailed the rhetorical tasks and offered guidance toward completing the inquiry assignments. Students used these resources in addition to the information provided to them throughout the course via the CD-ROM, course lectures, laboratory sections, and the course textbook.

A central task of representing their country at the Earth Summit was the production of the two technical papers. These papers, focused on geological hazards and the earth's climate, required the integration of real earth data into systematic arguments supporting a central thesis. The first of the two papers required students to select a country and develop a scientific argument characterizing the geological features in terms of plate tectonic activity. Students were expected to explore the geological hazards, given the conditions established through the application of plate tectonic theory and uses of relevant data, in terms of the political, social, and economic impacts such hazards posed for their country. Student arguments were supposed to be evidence-based, requiring students to include geological data, such as earthquake location and depth, volcanic location, and depth profiles, captured from the interactive CD-ROM. The point of the paper was not to merely offer a characterization of the geology of a country (a conclusion), but to make an argument with relevant data regarding the theory of plate tectonics for the specified region.

The second writing assignment allowed students to select an earth climate issue affecting their focus country. In this case, the students were expected to employ the same evidence-based argumentation practices as in the first paper. Students were required to include earth data that is available from a variety of sources, although students primarily used data available on the Internet and from the computer visualization program, WorldWatcher (Edelson, 2001). This task offered more freedom of choice of topic. The range of suggested topics included climate biozones, precipitation patterns, pollution, wind patterns, ocean circulation patterns (e.g., effect on local weather), effects of global warming on a particular country, what a country adds or does not add to global warming, ice cap melting and sea level changes, yearly events (e.g., monsoon and other seasonal events), effects of El Niño and La Niña, ozone hole effects, variations in precipitation (drought/deluge), volcanic eruptions affecting local conditions (e.g., Mt. Pinatubo eruption), and changes in albedo (deforestation, melting ice caps). The range of the topics and the sort and types of data relevant to the task rendered this task considerably more open for the student writers.

In order to meet the university writing requirement, both papers combined had to total 1800 words. Papers are approximately 6–10 pages of double-spaced text, including numerous hyperlinked data inscriptions drawn from the multiple data-sets provided by the CD-ROM, Internet, and/or WorldWatcher. The enhanced learning environment, created by the use of the EarthEd software, provided students multiple tools for creating scientifically sound arguments regarding the point of view of their chosen country. More information about the CD-ROM may be found at http://EarthEdOnline.org/.

Research Context and Methods of Data Analysis

The study draws from student papers that were available from three consecutive implementation of the oceanography course (Spring 2003, Winter 2004, Spring 2004). The primary data used for our analysis were the student produced written arguments in the form of the two technical papers. We took a random sample of 15 authors for each of the two writing assignments. We were able to access the papers in electronic form complete with hyperlinks to all inscriptions (data diagrams, graphs, maps, models, photographs). This analysis was informed by other relevant course artifacts as described earlier such as the online course webpage, the course laboratory manual, samples of student work collected during participation in course activities, and informal interviews with participants.

Our research approach consists of three components, oriented around analysis of the eight epistemic and rhetorical criteria for science writing, as defined in this disciplinary and educational context. First, we examined the structure of the arguments. This was done by tracing the rhetorical moves made on each data inscription included by the student authors. Each inscription was identified and a code was entered into an Excel spreadsheet. We noted whether each inscription was acted upon by the student, including the extent to which the inscriptions were inserted, identified, and described in the descriptive portion of the student papers (labelled "observations" following the prescribed convention) and the extent to which these same inscriptions were inserted, identified, described, made relevant, and used as a warrant in the students' explanation (labelled "interpretations" following the prescribed convention). These charts were created for each student argument (n = 15 times 2 papers) to readily identify the lines of reasoning and the empirical support marshalled by the student authors. The number of data inscriptions, models, and other figures was identified and tabulated.

Second, in order to assess the epistemic criteria for each paper we identified the thesis statement and lines of reasoning, based on the structural analysis and carefully rereading each paper. Through this process of reading we rated each paper on a set of 17 questions, show in column three of Table 7.1. For each dimension the students' argument was rated on a scale from 0 (non-existent) to 4 (excellent). This level gradation was chosen to match the specificity that can be reasonably deciphered given the built-in ambiguity of the writing tasks. This analysis was done for both papers (plate tectonics, earth's climate) for each of the 15 students across two analysts. We next build factors related to the eight criteria mentioned early regarding the normative assessment of argument strength. These eight criteria were operationalized by building factors from the 17 questions posed of the student arguments, as follows:

1. Solvable research question or thesis statement (Questions 1, 2)
2. Lines of reasoning that are convergent (Question 5)
3. Lines of reasoning that are sufficient (Questions 3, 4, 10)
4. Lines of reasoning that are built with valid inferences (Question 16)
5. Progressive construction of evidence (Questions 6, 7, 8)
6. Coherence across and within lines of reasoning (Questions 12, 13, 14)
7. Coordinated evidence across epistemic levels (Questions 9, 11, 15)
8. Thesis is supported (Question 17)

Third, based on the initial quantitative results across the 30 papers we chose 4 papers, for which there was high inter-rater reliability and variation in adherence to the genre conventions, in order to examine variation in task engagement in detail. These cases are presented in the results section. By diagnosing the ways that students are both able to write evidence-based arguments as well as ways they fail to do so, we derive instructional implications.

Results

We present our findings in two parts. First, we examine trends across the 30 papers. Second, we present case studies generated by close scrutiny following quantitative assessments.

Trends across Papers

There was a general pattern for the student writers regarding the strength of their arguments across the two writing assignments. Two patterns are evident. First, there were more papers scoring high (averaging between 3 or 4 points per question for criteria shown in Table 7.1) for the plate tectonics paper as compared to the earth's climate paper. The distribution of student scoring categories for the plate tectonics paper was 7 high, 3 mid-range, and 5 low; while the distribution of student scoring categories for the earth's climate paper was 4 high, 5 mid-range, and 6 low. Through the sequence of writing the plate tectonics paper and then the earth's climate paper only two students scored in a higher category on the earth's climate paper, 8 remained in the same scoring category, and 5 scored in a lower category.

Second, across the two writing assignments, there was a clear difference in the number of data inscriptions between poorly argued papers and well argued papers. Low scoring papers averaged 4.4 inscriptions per paper, while high scoring papers averaged 9.7 inscriptions per paper. While there is considerable variation among the high scoring papers, the general pattern holds that poorly evidenced papers used less data. This seems to be a rather obvious conclusion,

Table 7.1 Analyses Criteria and Student Scores for Two Writing Tasks (Plate Tectonics (PT) and Earth's Climate (EC) Papers) for Four Case Studies (0 = Minimum, 4 = Maximum)

Dimensions of Analysis			Scores for Four Cases							
			Student Writer 1		Student Writer 2		Student Writer 3		Student Writer 4	
Feature of Arguments	#	Questions posed of student arguments	PT	EC	PT	EC	PT	EC	PT	EC
Thesis	1	Is the thesis clearly stated?	3	3	4	4	3	4	3	4
	2	Does the thesis show solvability?	4	3	4	4	4	3	2	4
Reasoning Structure	3	Are there multiple lines of reasoning?	1	1	4	4	4	2	2	3
	4	Are the lines of reasoning plausible given the scope of the thesis?	3	0	4	4	4	2	3	3
	5	Do the lines of reasoning converge to a conclusion?	1	0	4	4	3	1	1	2
Observational Evidence	6	Are appropriate data representations inserted?	1	1	4	4	4	3	2	3
	7	Are data representations identified?	1	1	4	4	4	2	2	4
	8	Are data representations described?	1	1	4	4	4	1	2	3
	9	Are the data used relevant?	2	1	4	4	4	3	3	4
	10	Are the data potentially sufficient?	0	0	4	4	3	1	1	2
Explanatory Evidence	11	Are the data identified (explicitly)?	0	0	4	4	4	0	1	3
	12	Are the data described as part of the explanation?	1	0	4	4	4	0	0	3
	13	Are the data used to describe a mechanism?	1	0	4	2	4	1	0	3
	14	Are the data used to support an explanation?	1	0	4	3	4	0	0	2
	15	Is the relevance of the data clearly identified?	1	0	4	4	4	1	0	3
	16	Are the inferences valid?	1	1	4	4	4	1	2	3
Conclusion	17	Is the thesis supported?	1	1	4	4	4	1	2	2
		Total score =	23	13	68	65	65	26	26	51
		Score category:	L	L	H	H	H	L	L	H

given the goal of producing arguments based on empirical data. Indeed, the overall correlation of number of data inscriptions and total score was r = 0.74 for the plate tectonics paper and r = 0.70 for the earth's climate paper. Nevertheless, the use of inscriptions alone does not make a strong argument. In one of the cases described below, a student created a significantly better argument for the second paper (earth's climate) with only one additional inscription.

Examination of Individual Cases

The four cases chosen for closer analysis represent four ways in which the student authors differentially adhered to the normative conventions of the genre as defined by this task. The overall scores for these four writers across the two papers are presented in Table 7.1. A breakdown of the epistemic and rhetorical criteria is presented in Table 7.2. Student writer 1 was categorized as writing weak arguments for both the plate tectonics and earth's climate paper (coded LL). Student Writer 2 wrote strong arguments in both cases (coded HH). Student Writer 3 wrote a strong argument for the plate tectonics paper, but was not able to do so in the context of the more loosely defined earth's climate paper (coded HL). Student Writer 4 showed the greatest improvement of all writers from the plate tectonics paper to the subsequent earth's climate paper (coded LH).

Student Writer 1 argued in the plate tectonics paper that there is a subduction zone along the west coast of Mexico. This thesis was well posed and potentially supportable. However, the student author considered only a limited amount of data (earthquake and volcano locations). The absence of elevation profiles to support the

Table 7.2 Scores of Four Student Cases along Criteria for Argument Strength by Factors (0 = Minimum, 4 = Maximum) for Plate Tectonics (PT) and Earth's Climate (EC) Papers

	Student Writer 1		Student Writer 2		Student Writer 3		Student Writer 4	
Criterion	PT	EC	PT	EC	PT	EC	PT	EC
Number of inscriptions: data, models	2, 0	2, 0	6, 1	8, 0	15, 3	5, 0	5, 0	6, 2
Thesis statement (solvable research question)	3.50	3.00	4.00	4.00	3.50	3.50	2.50	4.00
Convergent lines of reasoning	1.33	0.67	4.00	4.00	3.67	1.67	2.00	2.67
Sufficient lines of reasoning	1.00	0.00	4.00	4.00	3.00	1.00	1.00	2.00
Valid inferences for lines of reasoning	1.00	1.00	4.00	4.00	4.00	1.00	2.00	3.00
Progressive construction of evidence	1.00	1.00	4.00	4.00	4.00	2.00	2.00	3.33
Coherence across and within lines of reasoning	1.00	0.00	4.00	3.00	4.00	0.33	0.00	2.67
Coordinate evidence across epistemic levels	1.00	0.33	4.00	4.00	4.00	1.33	1.33	3.33
Support for thesis	1.00	1.00	4.00	4.00	4.00	1.00	2.00	2.00
Overall rating category score (low, medium, high)	L	L	H	H	H	L	L	H

minor claim of a characteristic trench and earth depth profiles left the lines of reasoning sparse. The author was left making high inference claims about characteristics of subduction zones in general with little or no data from the actual geographic location. The argument was thus comprised of claims of high epistemic level without the needed coherence, coordination, and progressive construction of data as evidence—this is evidenced in Table 7.2 for Student Writer 1, PT column. Interestingly, the thesis is essentially true, but lacking the expected evidentiary support expected for the task at hand. Student Writer 1 offered a similar argument for the earth's climate paper. In this case, the student writer identified as a thesis that Mexico has a water and air pollution problem. Much of the paper focused on the production of CO_2 gas. However, there was only one relevant data inscription (along with photographs of smoggy cities). Even this one piece of data was not used well; it was not described in a way that connected the pollution thesis to its relevance.

Student Writer 2 offered well-argued positions in both papers. Across the epistemic and rhetorical criteria, this student scored high (see Table 7.2). In the plate tectonics paper the student argued that Japan lies on a convergent boundary. The case was made by reference to six inscriptions (two of which included multiple profiles) referring to elevation, earthquake, and volcanic data. Importantly, the data were argued as evidence through the rhetorical progresses of making coherent claims, coordinating data and claims across epistemic levels, and progressively building the case with explicit reference to previously established claims. See Table 7.2, column Student Writer 2, PT. A similarly organized argument was made for the earth's climate paper in which the student writer examined the contribution of Japan to CO_2 emissions and thus global warming. Multiple data inscriptions were presented regarding population density, CO_2 emissions, and surface temperature. As in the previous case, the student scored high on the epistemic and rhetorical criteria, see Table 7.2 column Student Writer 2, EC.

The next two cases are particularly interesting as in both cases the student writer scored significantly different across the two tasks. In the first case, Student Writer 3 was able to create a substantially supported argument for the plate tectonics paper, but was much less able to do so for the earth's climate paper. So what was different? Table 7.2 (column Student Writer 3, PT & EC) offers some clues. For both papers the student was able to create a reasonable thesis statement (regarding the geology and greenhouse emissions and their consequences for the United States). In the plate tectonics paper the student developed multiple lines of reasoning, including the use of earthquake locations and depth profiles across multiple areas, volcano locations, and elevation profiles. These lines of reasoning were tied to the thesis through the coherence, coordination, and progressive construction of evidence typical of well-formulated arguments (see Table 7.2, column Student Writer 3, PT). The earth's climate paper was not able to make the case for the thesis. The thesis was considerably broader: "Emission of greenhouse gases leads to the greenhouse effect, temperature and climate change, and environmental disaster." Given this thesis, one problem with the overall argument is the relationship of the thesis to the data. The thesis refers specifically to the United States, as specified in the assignment.

But the data are for CO_2 emissions worldwide. Little of the data are tied specifically to the US contribution to CO_2 and thus global warming (one inscription stands without comparison to global data offered subsequently). Furthermore, only one graph is presented regarding temperature (for global temperature as correlated to CO_2 emissions). Thus, the lines of reasoning are not sufficient—there is little information about temperature and climate change. The lines of reasoning are not fully valid as the thesis refers to the United States, while the data refer to global variables. These are shortcomings of the epistemic criteria. Similarly, the student was not able to coordinate the claims and develop coherence (see scores for coherence and coordination on Table 7.2). The data are generally identified, described, and shown to be relevant by the writers; however, the interpretations do not make reference to data, but rather speculate on the ills of global climate change. Interestingly, this sort of argument is not beyond the scope of the specific task. Rather, this speculation would need to be supported by the data presented to be evidence based, and not just opinion or unjustified conclusions.

The fourth case we present is the student that showed greatest improvement from the first paper (plate tectonics) to the second paper (earth's climate). For the plate tectonics paper the student writer attempted to make the case that Vietnam is located on the Eurasian plate and that the boundaries of this plate are the Philippine and the Indo-Australian plates. In addition the student set up the argument to include the possibility of underwater earthquakes and flooding due the topography of Vietnam. This broad thesis statement showed some ambiguity and this may have set the stage for a poorly formulated argument. The author developed lines of reasoning based on elevation profiles, earthquake locations and depth profiles, and volcanic locations. The results presented in Table 7.2 (column Student Writer 4, PT) again offer some insight into the diagnosis of the weaknesses of the argument. The argument was rated low for developing sufficient lines of reasoning, coherence, and coordination. While the lines of reasoning were plausible (the case could have been made with these types of data), for locating Vietnam on a particular plate, there was little offered regarding the underwater earthquakes and possible flooding. There were also weaknesses in the rhetorical presentation of the data in the argument. The relevant earth data was not coherently tied to the students' interpretations. One way to characterize the issue is that the student made high-level claims about the geological data concerning the location of Vietnam on its plate, without making explicit the ways that such data could count as evidence.

For the earth's climate paper the student was able to marshal evidence for the central thesis regarding the weather patterns of Vietnam in relation to the monsoon seasons. Data were presented regarding wind patterns, rain, and temperature. In this case, the rhetorical features of a strong argument were present. The student was able to draw on data inscriptions and identify, describe, and base explanations on these inscriptions across the paper sections and epistemic level of claim. For this paper, unlike the plate tectonics paper, the student's interpretations make explicit reference to data and build from descriptions of the inscriptions to mechanisms for changes in the seasonal weather patterns for Vietnam. See Table 7.2, column Student Writer 4, EC.

Summary of Analysis

From reading the 8 papers by the four authors in the case studies, and the remaining 22 papers, we are able draw some conclusions about patterns in the data. Well-evidenced arguments tended to be focused in scope, convergent, and explicit. In these papers, students demonstrate an understanding of the unique rhetorical demands of the scientific paper. Argumentation strategies employed by student writers include the use of multiple and converging lines of evidence based on valid inferences. Furthermore, these lines of reasoning are well identified and annotated in the text. Data entered as observations were explicitly referenced later in the paper as students extended their arguments through their interpretations drawn directly from their data. Generally, these students clearly illustrated the relevance of the data to their overall argument, using the data as warrants.

Poorly evidenced arguments can be of three sorts. The first sort of argument suffers from vague reference to supporting data. These examples include students who used converging lines of evidence, which were both identified and described in the text, but were only referred to generically in the interpretation section. For example, a student might refer to “the data” or to “the volcanoes” without explicitly directing the reader to the data they had previously presented. Furthermore, while the relevance of the data to the students’ argument was evident, the reader was required to make interpretations regarding the relationship between the students’ evidence and their argument. The second sort of poorly evidenced arguments were those who may have used multiple data references and/or converging lines of evidence yet failed to create an argument based on this evidence. In this case, the data presented did not fit coherently with the argument; there was a mismatch between the thesis statement and the putative evidence supporting it. The third sort were those arguments written by students who referenced intangible evidence, including minimal data. In this case, the interpretations were based on evidence that was not presented to the reader. These student writers tended to use textual references in place of data.

Discussion

In this chapter, we referred to a variety of issues regarding the uses of argument in science education. First, we discuss the value of demystifying the epistemic and rhetorical features of scientific arguments. We use the study to consider how to contribute to research on argumentation. Second, we consider the differences in the student writing given the differential complexity of the two tasks. Variation in the students’ abilities to argue the two cases may confound their learning through the engagement with the tasks with a change in the task demands. Third, we discuss some unique contributions of tools and argumentative supports provided from the oceanography course. Fourth, we discuss the broad issue of preparing students to engage with socio-scientific issues.

In the study presented, we sought to move beyond studies that examine the claims and relevant evidence for student arguments to consider the argumentative structure and the ways that epistemic criteria may be brought to bear on the assessment of student writing. The rationale for the two writing assignments in this course derives from the need for citizens to develop the skills of using, assessing, and critiquing evidence in scientific arguments. In other words the goal is to address this need through numerous opportunities to use, assess, and critique evidence in scientific arguments. We have argued that to formulate an evidence-based argument students need to pose a research question, develop multiple lines of reasoning that are sufficient, convergent, and supported by valid inferences across epistemic level of claims. The highly organized student writing samples varied in the ways that data were tied to the central thesis argued by the student author. Through close examination of the four cases, we noted variation in the ways that writers developed cohesion across claims, coordinated claims across epistemic levels, and constructed their arguments from data. These rhetorical features (coherence, coordination, and progressive construction) offer insight into how argumentation can be taught to students. Our analysis seeks to make visible epistemic practices of science not readily available to students. These ways of proposing, justifying, evaluating, and legitimizing knowledge claims are embedded in a particular community and are social knowledge, learned through participation (Kelly, 2005; Kelly & Green, 1998).

Second, for the second writing task involving the earth's climate, students were required to work in a broader problem space. The topics and range of data were more varied and potentially more complicated. Our analysis identified how students struggled more in the second context adhering to the argument conventions. However, given the broader nature of the task, and the range of possible ways to attempt to complete the task, the lack of equally tight evidential arguments in not surprising. The earth's climate papers did, however, show evidence of adherence to the genre, use of data, and respect for evidence. The extent of the student learning is confounded by the change in the task demands—these demands were purposely changed to support the course goals and challenge the students to argue in a new arena.

Third, in reading Sadler's (2004) comprehensive review of socio-scientific argumentation, we noticed that few of the studies cited required students to use large-scale data sets, and fewer still provided discipline-specific, mediational tools to support argumentation. Nevertheless, Zohar and Nemet (2002) identified ways that support for argumentation can lead to improved results. This suggests much potential for use of complex data-sets and importantly, developing ways of supporting argumentation through research and development. The developmental cycles supporting our work on written argument have identified the potential for students to engage in situations where they can pose open-ended, researchable questions, pursue such questions (without the inconvenience of contrived answers, known to the teacher) to their logical end, and be held accountable to their claims by peers and instructors. A continued research direction remains the development of tools that can mediate the knowledge and practices of science and offer students ways of understanding that transfer to other, similar socio-scientific contexts.

Fourth, we discuss how argumentation may be related to students' decision-making. Research to date has tried to identify how uses of argumentation support socio-scientific decision-making or how students' conceptions of the nature of science influence their decisions regarding socio-scientific issue (for review see, Sadler, 2004). While our study does not attempt to measure changes in students' decision-making, we have offered a unique approach to the issue of developing sophistication regarding socio-scientific issues. The rationale for the course, along with associated mediational tools, is to inculcate some relevant epistemic practices—ways of proposing, evaluating, critiquing knowledge claims from a disciplinary point of view—through engagement with rich data-sets and social circumstances where evidence is valued. The educational process included learning the epistemic practices associated with creating sound arguments through the first major writing assignment (plate tectonics) before entering into a situation where science meets social issues more directly (such as global warming). Thus, the students had a set of disciplinary practices that could be brought to bear on the more complex and nebulous task of the earth's climate.

Fifth, the uses of argumentation in university teaching may support greater uses of written communication in secondary classrooms. Secondary science programs often set expectations for curricula choices, instructional strategies, and assessment techniques based on university entrance requirements. Examples of evidence use and scientific genres in university courses, such as this oceanography course, may model reasoning processes and epistemic practices that can be emulated in secondary education. Such examples provide support for writing for learning science in secondary education where little is known about how "secondary teachers use scientific genres, their goals and purposes for using these genres, their expectations for student products" (Keys, 1999, p. 128). Argumentative discourse may be one strategy among a range of writing processes that support writing for learning science (Prain, 2006). Furthermore, the connections across the range of spoken and written discourses in secondary and tertiary science education remain an area of importance for discourse-oriented research as cognitive and epistemic learning is embedded in and mediated through social interaction and cultural practices (Kelly, in press).

Conclusion

Drawing on research emphasizing the importance of written communication for the development of scientific knowledge in schools and other settings, we propose providing opportunities to develop and practice argumentation strategies to prepare students to engage in socio-scientific practices extending beyond the scope and limitations of the undergraduate classroom. Specifically, we maintain that, given opportunities to evaluate, interpret, and use data within a specified rhetorical task, students may be able to apply their ability to use evidence-based argumentation strategies regarding broader topics as active citizens (Cross & Price, 1999; Jenkins, 1999). While previous research regarding science and writing has focused on how and why writing can be used to enhance learning opportunities for students of science, our work extends the current paradigm by documenting specific epistemic and rhetorical strategies that students can employ to successfully prepare an evidence-based scientific argument.

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