# Demystifying Disciplinary Writing: A Case Study in the Writing of Chemistry

**Fredricka L. Stoller, James K. Jones, Molly S. Costanza-Robinson, and Marin S. Robinson, Northern Arizona University**

Concerns about students' writing abilities, beyond those addressed in first-year composition, have motivated developments in the Writing Across the Curriculum (WAC) and Writing in the Disciplines (WID) movements. The WID movement, in particular, has led to a growing number of writing courses housed within disciplinary curricula, including chemistry (the focus of this article). In these courses, faculty assist students in developing their writing abilities while articulating an "understanding of content in genres appropriate to professional audiences" (Carpenter & Krest, 2001, p. 47). This commitment to the development of writing abilities and the learning of content through discipline-specific genres, hallmarks of the WID movement, helps move students toward becoming members of the discourse communities associated with their academic disciplines. The advantages of this pedagogical orientation are many; one benefit worth noting has been captured by Carpenter and Krest (2001) who affirm that when science students, as an example, study writing within their own disciplines, they view themselves "as scientists learning to write rather than students in a writing class in which they are permitted to write about science" (p. 62).

A decade ago, Stockton (1994) suggested that the WID approach helped to demystify the relationship between scientific language and scientific knowledge. Although Stockton was referring to writing and content knowledge in biology, numerous chemical-education publications confirm that chemistry faculty are grappling with ways to teach writing and, at the same time, demystify the language and content of chemistry in lower- and upper-division chemistry courses (e.g., Beall & Trimbur, 2001; Coppola & Daniels, 1996; Driskill, Lewis, Stearns, & Volz, 1998; Gordon et al., 2001; Kovac, & Sherwood, 2001; Paulson, 2001; Shibley, Milakofsky, & Nicotera, 2001).

The challenges associated with addressing students' disciplinary writing have become more pronounced as increasing numbers of nonnative English speakers enter the sciences (Jacoby, Leech, & Holten, 1995; Matsuda, 2001). Linguistically diverse students often face challenges that influence their writing performance, challenges deriving from limited experiences in academic writing as well as potentially limited knowledge of vocabulary, language structure, content, and so forth (see Grabe & Kaplan, 1996; Matsuda, 2001). Yet, while we might think that linguistically diverse students have many more disciplinary-writing needs than their native speaking counterparts, in fact, in chemistry, much like other sciences, both native and nonnative students need training and practice in the writing of their disciplines, the difference being "one of degree rather than kind" (Levis & Levis, 2003, p. 212; see also Bereiter & Scardamalia, 1987; Matsuda, 2001). Rarely, if ever, are undergraduate science students exposed to specialized academic discourse nor are they required to write in genres generally associated with the discipline. Thus, neither native speakers nor linguistically diverse students have had the opportunity to develop knowledge of the conventions of


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disciplinary genres, including their rhetorical plans and organizational logic (see Grabe & Kaplan, 1996). Students in the sciences (whether they are native or linguistically diverse students) typically learn to write "for the discipline" in an ad hoc manner during doctoral training (Learning to speak and write, 2001). Because of this delayed attention to disciplinary writing, many less experienced students have the mistaken impression that they will not need to perfect their writing skills for their academic lives or careers as chemists. Yet, as many career chemists affirm, writing plays an important role in their professional lives; thus, there is a need to view "writing as integral to the process of doing and learning chemistry, rather than as a tangential activity" (Klein & Aller, 1998, p. 31). Fortunately, the literature suggests that writing enhances the learning of content rather than distracts from it (Klein & Aller, 1998).

In this article, we describe steps taken to demystify the writing of chemistry as part of the development of a junior-level writing course for chemistry majors at Northern Arizona University (NAU).[1] Although the course is offered by the chemistry department, its conception, development, implementation, and assessment have been the result of an interdisciplinary effort among course-development team members from both chemistry and applied linguistics (the latter housed in NAU's English department). To describe the process of demystifying the writing of chemistry, we first provide a brief description of the course that we have developed over the last four years. We then focus on the steps taken thus far to demystify the writing of chemistry for three primary groups:

- *chemistry faculty* who have little experience teaching writing
- *applied linguists*, on the course-development team, who have little, if any, chemistry knowledge
- *junior-level chemistry students* who have had little, if any, exposure to and experience with the professional genres of chemistry

It is beyond the scope of this article to delve into all aspects of the course development process and the actual instruction and assessment components of the course. Nonetheless, it is our hope that this discussion will offer insights into steps that can be taken by interdisciplinary course development teams to better understand the language and writing conventions of discipline-specific writing. Such an understanding, in turn, should inform instructional and assessment practices that will assist native and linguistically diverse students gain access to the literacy demands of their chosen disciplines.

## Writing Like a Chemist: A Course Description

The Writing Like a Chemist course at Northern Arizona University was initially conceived as a response to a university mandate to address the writing needs of junior-level students across campus. At the time of the mandate, departments were given the option of either developing junior-level writing-intensive courses of their own or requiring students to take junior-level writing-intensive courses offered by the Rhetoric, Composition, and Professional Writing faculty in the English department. The chemistry department chose to develop a course of its own, but not by itself. The chemistry department faculty member who spearheaded the course-development process initiated a "cross-disciplinary alliance" (Wardle, 2004) with an English department faculty member, associated with the applied linguistics area within the English Department, who had expertise in English as a second language, literacy skills, large-scale curriculum design, and materials development. The project development team has expanded over time to include two doctoral students in applied linguistics, a post-doc in Chemistry, an assessment consultant, a web consultant, and a number of project evaluators from chemistry and Rhetoric, Composition, and Professional Writing. The course-development process, initiated in 2001 with the support of the National Science Foundation (NSF), has since taken on more ambitious directions. In 2004, with additional NSF support, a nationwide pilot of the Writing Like a Chemist materials began. The piloting process will continue through spring 2006.

The Writing Like a Chemist course has been defined by a fairly traditional set of course objectives:

- Students will produce papers with proper word choice, adherence to scientific writing conventions, correct grammar, and few mechanical errors.
- Students will produce papers with clear organizational structure (within paragraphs and sections), with appropriate information in each section.
- Students will produce papers with clearly organized and properly formatted graphics (schemes, tables, and figures).
- Students will adapt their writing styles for different audiences and will produce papers with the detail and conciseness appropriate for each audience.
- Students will produce papers that convey a clear and correct understanding of science and appropriately paraphrase other scientists' work.
- Students will reflect on their strengths and weaknesses as writers, recognize the importance of revision in writing, understand that writing is a collaborative process, and develop increased self-confidence in their literacy skills.

Although the objectives are stated in rather product-oriented terms, the course adheres to a process-oriented pedagogical framework that guides students through the various stages of writing (including pre-writing, drafting, revising, self-editing and peer editing). To meet these objectives and remain true to our process orientation, a three-module course has been developed, with each module focusing on the reading and writing of a different chemistry genre: the journal article, poster presentation, and research proposal. Each module includes reading and writing tasks that make use of authentic excerpts from the targeted genre. Students are asked to read these model texts multiple times and, through in-class and out-of-class tasks, analyze their science content and the ways in which the authors' purpose and intended audience are addressed through organizational structure, language (i.e., word choice, grammatical features, writing conventions), and communicative function. The pedagogic emphasis here has been on "enablement, facilitating access to valued genres through tasks designed to raise students' awareness of text features" (Hyland, 2002, p. 20).

At the core of each module is a multiple-step assignment that requires students to write multiple drafts of the targeted genre, modeled after authentic counterparts. (See Charney & Carlson, 1995; Johns, 1993, 1995, 1997, 2002; Kuldell, 2003; Smagorinsky, 1992; and Stolarek, 1994, for discussions of the use of models and modeling in writing instruction; these topics are also addressed later in this article.) For example, in the journal article module, students write a data-driven paper “modeled after articles in peer-reviewed American Chemistry Society (ACS) journals” using data from their own research or "canned research" (described below). Papers are drafted one section at a time, in the order most often written by career chemists (i.e., Methods, Results, Discussion, Introduction, Abstract). Toward the end of the module, students merge the different sections, making the changes necessary to create a coherent whole. In brief, the multiple features of the course have coalesced into a "read-analyze-write" approach, whereby students read (and reread) authentic texts from the targeted genre, engage in genre analysis activities, and then write (and rewrite) a piece of their own that follows the scientific and language conventions expected by the discipline.

The course syllabus and corresponding materials, from the very start of the project, have been designed with students from different linguistic, educational, and cultural backgrounds in mind. Our goal has been to create a course that is accessible to linguistically diverse students, but that does not water down the content or objectives of the course. Essentially, we have strived to enable all students to meet the conceptual and linguistic demands of the course. Beneficial for linguistically diverse students, as well as native speakers, are features such as the following: illustrative excerpts from the primary literature, with explanatory notes; graphic displays of important points; pre-writing activities and post-writing reflection tasks; guided reading assignments; sidebars in the coursepack with information that clarifies new lexical items and scientific concepts, as well as unfamiliar writing conventions; and supplementary "language tips," with accompanying exercises, on areas of language that have proven particularly challenging for students (e.g., the differences between affect/effect, comprise/compose, less/fewer, since/because; hyphenated two-word modifiers; plural/singular scientific words; subject/verb agreement in complex sentences).

## Approaches to Demystifying the Writing of Chemistry

In the process of developing the Writing Like a Chemist course, we have come to realize that in addition to our more traditional course objectives (stated above), one of our primary goals has been to demystify writing in the discipline of chemistry for students; to do so, we have needed to demystify chemistry writing for course-development team members (chemists and applied linguists) as well. It will come as no surprise to those interested in WID that few, if any, junior-level chemistry students (both native speakers of English and linguistically diverse students) have had the opportunity to read the primary literature or write in the professional genres of the discipline. As a result of this limited exposure, these students are familiar, almost exclusively, with introductory textbooks and lab manuals, which have little, if anything, in common with the professional genres of the discipline (Johns, 1997; Myers, 1992). Equally important has been the goal of demystifying the teaching of writing for chemistry faculty who have little or no experience teaching writing. Although most chemistry faculty write for professional purposes, they are, in general, inexperienced in teaching writing and are unaware of what aspects of their own writing are based on personal preferences rather than on consensus in the discipline. It goes without saying that part of the course-development process has also involved taking away the mystery of chemistry writing for course-development team members from the field of applied linguistics who had little, if any, knowledge of chemistry before beginning the project. Our ultimate aim, however, has been to develop a course and corresponding materials that (a) enhance the writing and reading skills of undergraduate chemistry majors, (b) are easy to use by chemistry faculty with no formal training in teaching writing, and (c) involve chemistry students and faculty alike in an effective pedagogical approach to writing in the discipline.

In this article, we share some of the steps that we have taken to elucidate the characteristics of chemistry writing for these various constituents. It should be noted that although we present our approaches to demystifying the writing of chemistry for these various groups separately and in a linear fashion, in actuality our steps have overlapped and have proceeded in a cyclical manner rather than a linear one. Throughout the process, our efforts to clarify the writing of chemistry for one group of constituents have informed our efforts to do the same for other constituents in multiple, and productive, ways.

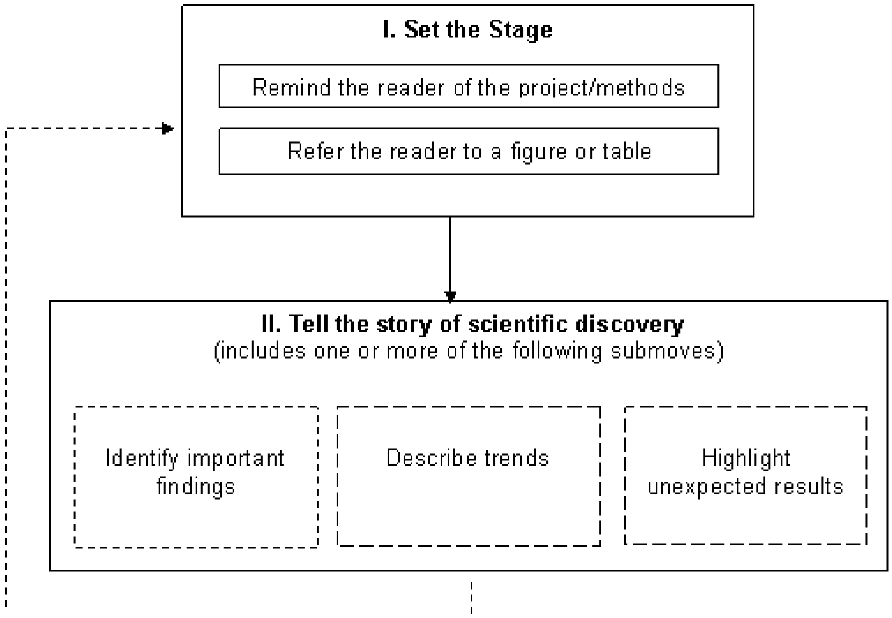
### Demystifying the Writing of Chemistry for Course-Development Team Members

Our course-development project, from the onset, has involved ongoing collaboration between chemists and applied linguists. In the first two years of the project, the course-development team consisted of one chemistry faculty member, one applied linguistics faculty member, and one graduate student with a growing expertise in corpus linguistics. In the third year of the project, a post-doc in chemistry joined the team; in addition, an assessment team (comprising an applied linguistics faculty member, with expertise in the theory and practice of first and second language writing and assessment, and a PhD student) was constituted to oversee project- and pilot-assessment endeavors. Our interdisciplinary approach has proven to be indispensable, in large part because each team member has brought a different, but complementary, orientation toward language, genres, writing pedagogy, assessment, and chemistry content to the project. For example, the applied linguistics team members had years of experience teaching writing to native and linguistically diverse students, assessing writing, designing courses and corresponding instructional activities, planning and implementing peer-group activities, conducting language analyses (though not with chemistry texts), and training English as a second/foreign language teachers to teach writing. The chemists, on the other hand, had extensive experience reading and writing different chemistry genres, knew the discipline-specific backgrounds of junior-level students, could select excerpts from the literature that would be comprehensible to students and illustrate key features of the genre, and could identify common problems that chemistry students have with disciplinary writing as well as the frustrations commonly experienced by chemistry faculty when dealing with students' writing (at undergraduate and graduate levels).

Our collaboration, from the start, has been built upon a positive orientation toward our differences, leading to a joint search for an understanding of the discourse of chemistry and effective course design (see Barron, 2003; Gray, 1989; Odell & Swersey, 2003, for discussions of interdisciplinary collaboration). The insights (and queries) of each member have helped to elucidate different aspects of the project. It is fair to say that our approach to disciplinary writing, in general, and the demystification of chemistry writing, more specifically, could not have been accomplished without the participation of both sets of team members. As a team, we have strived to create a disciplinary writing course, with corresponding instructional materials, that is accessible to junior-level chemistry majors, chemists, and applied linguists.

As an example of one of our most important collaborative activities devoted to understanding the language of chemistry, team members have dedicated much of their time to analyzing the genres targeted for instruction. Our approach has been grounded in the work of the English for Specific Purposes school of genre analysis (e.g., Belcher, 2004; Bhatia, 1993; Swales, 1990; for a discussion of various approaches to genre analysis, see Hyon, 1996). Early in the project, the applied linguists introduced the chemists to the concept of genre analysis and trained them to analyze genres in terms of context, organizational features, lexico-grammatical features, and scientific conventions. The chemists then conducted analyses that required an understanding of chemistry content and suggested additional features for further investigation. As a result of these sustained genre analysis efforts, we have identified the most common moves in the standard sections of chemistry journal articles, posters, and research proposals. Following the work of Swales (1990) and Connor and Mauranen (1999), we have illustrated, in a clear visual manner, the structural features that contribute to the flow of different sections of targeted genres (see Figure 1 for an example of one of the move structures developed for the course). The visualizations themselves have clarified common organizational features of the targeted genres for the course-development team, leading to the development of purposeful instruction and useful teacher-student class discussions. The move diagrams have served as excellent pedagogical tools for introducing and reinforcing widely accepted conventions (and their variations) within the discipline.

*Figure 1. The move structure of a typical Results section in a chemistry journal article (Dotted lines indicate submoves and repetitions that are not required in all instances.)*




Another major step toward understanding the language of chemistry has involved the use of tools from the field of corpus linguistics. Corpus linguistics provides an empirical way for linguists to investigate aspects of language through the computerized analysis of large, principled collections of texts known as *corpora*. Computer programs are used to describe the texts that make up a corpus by identifying the frequency of occurrence of particular lexical or grammatical features and by examining the ways in which features co-occur. (Appendix A illustrates how concordancing software can be used to examine patterns of co-occurrence.) A 1.5 million-word corpus of chemistry texts, representing some of the genres of chemistry being targeted for instruction, was created (see Table 1). The use of this large database of discipline-specific texts has enabled an analysis of the language of chemistry of a scope not otherwise feasible. The corpusâ€”made up of 200 refereed journal articles, 240 sections of articles (i.e., abstracts, introductions, methodology sections, and results/discussion sections), and 132 popular chemistry articlesâ€"has made it possible to analyze the language of chemistry (e.g., lexico-grammatical usage and frequencies, contexts in which particular words or structures occur) in order to identify common and generalizable linguistic patterns. We have also used the corpus to verify the intuitions of our chemistry team members and access illustrative examples of key features of the language of chemistry for instructional purposes.

**Table 1. Corpus of Chemistry Texts Developed to Analyze the Language of Chemistry**

| Genres | Number of Texts | Number of Words |
|---|---|---|

| | | |
|---|---|---|
| Chemistry Journal Articles | | |
| Full-length refereed journal articles (from journals such as Journal of the American Chemical Society,Journal of Organic Chemistry, Journal of Physical Chemistry) | 200 | 991,606 |
| Sections of refereed journal articles (i.e., abstracts, introductions, methods, results & discussion sections) | 240 | 297,407 |
| Popular Chemistry Articles | | |
| Full-length popular chemistry articles (published in *Nature*, *Science*, *Science News*) | 132 | 157,344 |
| Total | **572** | **1,446,357** |

In more specific terms, our corpus has allowed us to examine targeted linguistic phenomena across numerous authentic chemistry texts. The goal has been to identify the most salient characteristics of these texts (and sections within them) and determine how they vary linguistically. We have used the corpus to study various aspects of the language of chemistry, including the following:

- Passives, nominalizations (i.e., nouns formed from verbs or adjectives, such as *distillation* from *distill* or *solubility* from *soluble*), pronouns, verb tenses, modals, and modifiers (e.g., only, even, almost, nearly, just)
- Lexical bundles (i.e., clusters of words that commonly co-occur, such as *as shown in Figure X*, *by the addition of*, *the temperature dependence of*)
- Syntactic frames (see Table 2 for an example of common frames for journal article titles)
- Vocabulary frequency and use (e.g., the most commonly used hedgesâ€”that is, words used to soften an interpretation or to show restraint, such as *indicate* and *suggest*; see Hyland, 1996, 2000, for more on hedging)

**Table 2. Common Patterns in Chemistry Article Titles**

| X | | Y | | Z |
|---|---|---|---|---|
| A Property, Role, or Effect of What Was Studied<br><br>A Research Method (stated or implied, e.g., "A Method for the Analysis", "An Analysis", "Determination") | of<br>in | What Was Studied | on<br>in<br>via<br>by<br>using<br>at<br>from | Target of Study or What Was Impacted in the Study<br><br>How/When/Where It Was Studied |

Examples

| | | | | |
|---|---|---|---|---|
| Crystal Structure | of | Native Chicken Fibrinogen | at | 2.7 Ã… Resolution |
| Heteronuclear Recoupling | in | Solid-State Magic-Angle-Spinning NMR | via | Overtone Irradiation |
| Time-Resolved Fluorescence Analysis | of | the Phtotosystem II Antenna Proteins | in | Detergent Micelles and Liposomes |

The corpus has also facilitated the search for authentic passages that illustrate rhetorical, linguistic, and scientific writing conventions typical of writing in chemistry, including the following:

- Rhetorical conventions (e.g., organization of whole articles and sections within them, level of detail, scope and depth of discussion, sequencing of given and new information)
- Linguistic conventions (e.g., the language of objectivity, subjectivity, description, conciseness; common singular and plural words such as data/datum, spectra/spectrum; commonly confused words among developing writers such as then/than, it's/its, affect/effect)
- Scientific writing conventions pertaining to, for example, the use of quotations; the specification of units of measurement; the presentation of data (e.g., nuclear magnetic resonance data, melting points, percent yield); the configuration and placement of tables, figures, and schemes; and the formatting of in-text citations and end-of-text references

The results of our analyses have assisted us in comprehending the intricacies of the language of chemistry, including the linguistic variation across different sections of a journal article. As a result of these efforts, we have been able to design instructional materials that include examples of naturally occurring structures and patterns of use in authentic chemistry contexts. Because of our use of the corpus, we have been able to develop materials that are based not on broad generalizations about the language of science or simply the intuitions of our chemistry team members, but rather on actual patterns of use in the genres of chemistry. (See Appendix B for an example of instructional materials that incorporate corpus findings.) Because intuitions and general perceptions about language, including the language of science, are often inadequate or incorrect (e.g., Biber, Conrad, & Reppen, 1994, 1998), the use of the corpus has made it possible for us to represent actual language use found in ACS journals and other key publications in the field.

In the coming years, we hope to incorporate additional genres into the corpus (e.g., funded grant proposals written by university professors, funded student grant proposals, poster presentations, student papers) to facilitate a broader analysis of the language of chemistry. An expanded corpus will make it possible to compare the writing of novice and professional writers in the field as well as language across different chemistry genres. (Readers interested in working with corpora of their own should consult Biber, Conrad, & Reppen, 1998; readers interested in creating and using specialized language corpora, e.g., disciplinary writing corpora, should also consult Bowker & Pearson, 2002.)

Another straightforward way to take the mystery out of chemistry writing has been to consult *The ACS Style Guide* (Dodd, 1997) and the ACS web site (www.acs.org), introduced to the team by chemistry members. The *Style Guide* has assisted the course-development team in identifying writing conventions that the field's premier U.S. organization considers important. Being able to make direct reference to the American Chemical Society and its endorsement of certain writing practices has added credibility to our approach among students (and, we assume, the chemists who are currently piloting our materials). We have also made use of the ACS web site and its links to chemistry journals. Each journal site includes instructions to authors, along with manuscript specifications. Because the field of chemistry does not endorse one single writing style, we have integrated exercises into the course to familiarize students not only with the many journals in the field, but also with their different writing specifications, all the while clarifying (and modeling) for students some of the steps taken by writers in the field.

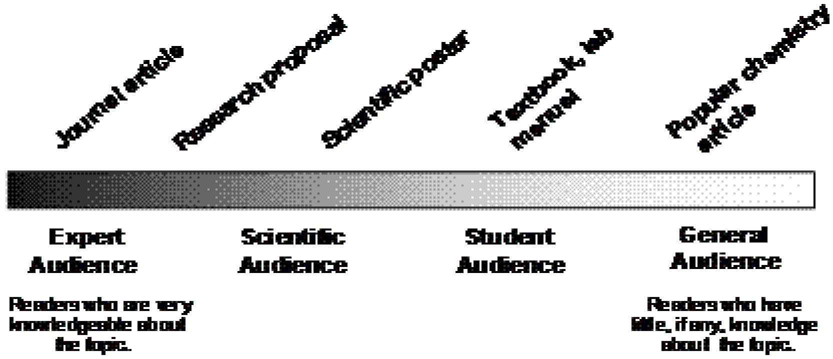
## Demystifying the Writing of Chemistry for Chemistry Students

The results of our interdisciplinary course-development efforts have helped to make the course accessible to native and linguistically diverse students. Certain practices have proven particularly effective in demystifying the language and content of chemistry for our students. These practices include using visuals for various instructional purposes; connecting reading, guided genre analysis, and writing; providing students with data, in the form of "canned research," to simulate the conditions required for writing an authentic data-driven journal article; and engaging students in activities to raise their metacognitive awareness. These practices are discussed in the following sections.

*Using visuals*. Of particular pedagogical value has been the incorporation of visuals into classroom instruction. We have used visuals to present new information, reinforce important concepts, and guide students in discovering aspects of chemistry writing on their own. (See Clarke, 1990, for a discussion of the value of graphic organizers in subject-area classrooms; Snow & Kahmi-Stein, 1996, for a discussion of the benefits of visuals for language-minority students.) As one example, we have used a simple continuum (see Figure 2) to depict, and reinforce, the range of genres that we focus on in relation to the degree of expertise of the intended audience (i.e., expert, scientific, student, and general audiences); this simple visualization was incorporated into instructional materials to support our prose discussion of the ways in which writing varies depending on the intended audience. Appendix B illustrates a different use of visuals; in Figure B.1, a graph is used to report the results of one of our corpus-based analyses, depicting the frequency of passive voice in four standard sections of a journal article. The graph was incorporated into instructional materials, in part, because graphs of many types are widely used in the sciences and are therefore familiar to chemistry students.

The move structures mentioned earlier identify, in unambiguous terms, structural features that contribute to the readability and flow of the sections of each genre. For instance, the move structure of a Results section (refer back to Figure 1) illustrates how writers move from "setting the stage" (by reminding readers about the project and/or methods, sometimes in a single sentence) to "telling the story of scientific discovery" (by, for example, highlighting unexpected results). Before drafting their own papers, students use these move structures as guides for analyzing authentic texts from the chemistry literature (a) to find sentences and/or paragraphs corresponding to the moves in the flow chart, (b) to identify the ways in which writers transition from one move to the next, and (c) to locate deviations in the professional literature. These visualizations of move structures raise students' consciousness about common discourse patterns in the articles that they read and guide students in the assignments that they write. We assume that these visualizations will serve as convenient reminders when students are writing on their own after completing the course.

*Figure 2. Visual used to illustrate a continuum of chemistry genres in relation to audiences with different degrees of expertise.*




*Connecting reading, genre analysis, and writing.* As an extension of the genre analyses completed by course-development team members, students are guided in genre analysis activities as well. Combining guided reading, the analysis of written texts, and writing tasks has helped to minimize the abstract nature of discussions about writing in the discipline. Students analyze authentic texts (actually excerpts from different sections of journal articles, posters, and research proposals) that have been incorporated into course materials as well as texts that they select themselves to gather background information for their own journal article, poster, and research proposal. The texts chosen by chemistry team members for genre analysis activities meet select criteria, including the following:

- Topic (general appeal, familiarity, potential relevance)
- Length (not too long)
- Challenge (not too advanced in terms of chemistry content)
- Authors (preference given to teams of native and nonnative authors)
- Writing conventions (adhering largely to our recommendations and those advocated in *The ACS Style Guide*)
- Variety (selected to represent a range of areas within chemistry including analytical chemistry, biochemistry, organic chemistry, agricultural and food chemistry, toxicology)

The excerpts chosen for genre analysis activities serve as models of preferential patterns and expectations of the discipline. While the use of models is not a popular pedagogical strategy among some writing professionals (see Ferris & Hedgecock, 1998; Grabe & Kaplan, 1996), others make strong cases for their use as pedagogical tools (e.g., Charney & Carlson, 1995; Cumming, 1995; Ferris & Hedgecock, 1998; Smagorinsky, 1992). Just like second language students who benefit from exposure to models that point out how language, text form, and certain discourse conventions are tied to specific purposes for writing (Grabe & Kaplan, 1996), more advanced writers (such as those in junior-level chemistry courses, native and nonnative alike) benefit from being exposed to models of discipline-specific genres. These models serve as frameworks, not as rigid templates or simple rhetorical formulae, for identifying (and later building) more complex routines and organizational patterns as students encounter more complex information and more demanding writing tasks (see Belcher, 2004; Ferris & Hedgecock, 1998; Stolarek, 1994).

Instructor-guided genre analysis activities (see Appendix C for examples) lead students to consider different preferential features of the target genres, in model excerpts, including the following:

- Context (with an emphasis on authors' purpose and audience)

- Organization, with special attention to broad structural features (i.e., sections and headings) and fine structural features (i.e., moves and transitions) following the work of Swales (1990)
- Language (including word choice, grammatical structures, and writing conventions)
- Scientific conventions (including the formatting of tables and figures, the use of numerals and/or words to express units of time and measure, spacing between a numeral and its unit of measure, the use of "a leading zero" with numeric decimals)
- Content (with an emphasis on the presentation of scientific content in prose and graphics, and the interplay between the two)

*Using "canned research" to guide student writing.* Another way in which we have both demystified the writing of chemistry and created a more realistic setting for writing has been through the development of "canned" research. Chemistry majors have typically completed only general and organic chemistry by their junior year; moreover, only a few have participated in undergraduate research by their junior year. With so little preparation for research of their own, it is unrealistic to ask students to write authentic and meaningful scientific papers, modeled after the journal articles that they are asked to read. To address this problem, the chemistry members of our course-development team have created "canned research" (cf. Sticker, 2002) based on (a) techniques commonly encountered in undergraduate chemistry curricula (e.g., gas chromatography/mass spectrometry or GC/MS, organic synthesis, ultraviolet-visible or UV-vis spectroscopy) and (b) research areas popular among students (e.g., biochemistry/biotechnology, forensics). The canned research includes information about the research area and fictitious (but realistic) results created specifically with the goals of a targeted writing assignment in mind (e.g., the journal article or poster presentation).

Canned research challenges students to write about projects that are more realistic than those typically encountered in laboratory courses. Through the use of canned research, students experience several of the actual steps taken by practicing chemists, making it possible for them to demonstrate substantially more depth and authenticity in their written work. For example, when completing a canned research project, students are required to

- read and cite the scientific literature
- make decisions about what details to include and what information to omit when writing for an expert audience
- analyze data based on model calculations provided
- organize a large body of data into meaningful tables and figures
- prepare graphics (tables, figures, and schemes)
- organize the text to tell a meaningful story of scientific discovery

Realism is further enhanced by the open-ended nature of the projects. In contrast to laboratory exercises, there is no single correct answer for a canned research project. Because students choose to organize their data differently and cite diverse sets of references, each paper constitutes a unique presentation of the research. Moreover, students take ownership of their canned research projects, as if they were authentic undergraduate research experiences. The use of canned research has proven to be an invaluable scaffolding technique for teaching chemistry as well as writing.

*Raising students' metacognitive awareness.* Another approach to demystifying writing in chemistry for students has involved raising students' metacognitive awareness of their own writing strategies, attitudes, and task experiences (see Hyland, 2002). Reflection activities, integrated into instruction through class discussions, group activities, and writing tasks, bring to the conscious level what students see in their own written work and the writing of others, how they perceive their own writing development and decisionmaking processes, and what they value about writing (see Appendix D for a sampling of reflective tasks). Reflection activities also raise students' awareness about the science that they have learned and the steps that they can take to improve their writing skills, reading abilities, and grasp of science. Because novice writers rarely begin courses such as ours with an awareness of their own writing processes (see Jacoby, Leech, & Holten, 1995) or reading abilities, these reflection activities have proven to be useful in uncovering the mysteries of the writing of chemistry and revealing students' gradually evolving reading and writing abilities.

## Conclusion

In this article, we have described steps taken to demystify the writing of chemistry as part of an interdisciplinary effort (among chemists and applied linguists) to develop an upper-division writing-intensive course for chemistry majors. Our efforts have served many purposes, among them building interdisciplinary linkages (see Samuels, 2004, on interdisciplinary bridges between the sciences and the humanities). Yet, the ultimate aim of these efforts has been to devise a discipline-specific course that meets the needs of not only native speaker and linguistically diverse chemistry majors but also the chemistry faculty intended to teach the course. Keys to the demystification process have included interdisciplinary genre analysis activities, the construction of a corpus of chemistry texts for analysis purposes, the identification of move structures typical of the targeted genres (i.e., the journal article, poster, and research proposal), the design of a read-analyze-write instructional approach using excerpts from the primary literature, the development of canned research, and the creation of metacognitive-awareness tasks for students.

The fruits of our efforts, thus far in the project, are being piloted (academic years 2004-2005 and 2005-2006) in a diverse sampling of public and private colleges and universities across the U.S.[2] The feedback provided by piloting faculty and students, in addition to samples of students' written work, should assist us in fine-tuning the approach, more generally, and instructional materials, more specifically, so that the course is accessible to chemistry students from different backgrounds and chemistry faculty with little experience in teaching writing.

The interdisciplinary approach described here has important implications for professionals interested in Writing in the Disciplines and Writing Across the Curriculum as well as for their native and linguistically diverse students. The merging of different but complementary orientations toward language, genre, writing pedagogy and assessment, and content teaching, by course developers from language-oriented fields and other disciplines, can result in innovative curricula that meet the varied needs of students and faculty alike.

## Appendix A

Screen-shot of Concordancing Software: Verbs that Commonly Co-occur with the Subject *We* in Chemistry Journal Article Introductions


## Appendix B

Examples of Instructional Materials that Incorporate Corpus Findings[3]

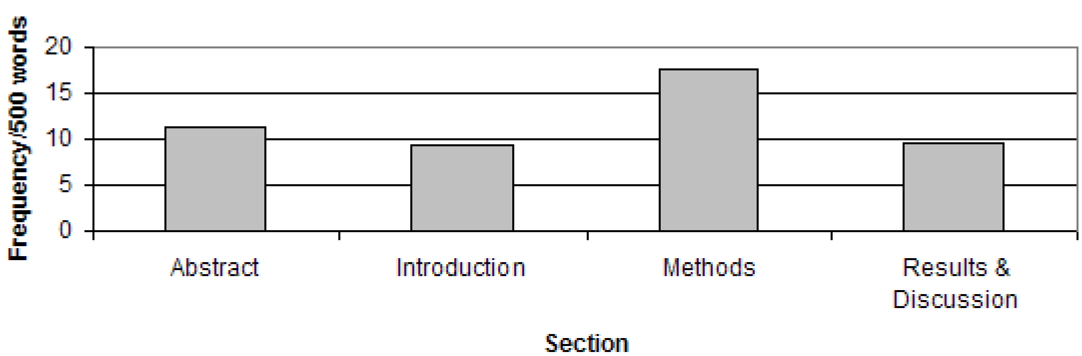



***Figure B1.*** *Frequency of passive voice in the sections of a journal article.*

*Note: These frequencies, the number of passive verbs per every 500 words, were determined through a computer-based analysis of 60 published chemistry articles, comprising approximately 300,000 words.*

**Table B1**. Passive voice, past tense verbs commonly used in Methods sections. [a]

| | | | |
|---|---|---|---|
| was added | was determined | was found | was recorded |
| was assigned | was dissolved | was isolated | was reported |
| was based | was dried | was measured | was shown |
| was calculated | was expected | was observed | was stirred |
| was carried out | was extracted | was obtained | was treated |
| was described | was filtered | was performed | was used |
| was detected | was formed | was prepared | was washed |

[a]These verbs were identified through a computer-based analysis of passive voice in a collection of 200 published chemistry research articles.

# Appendix C

Examples of Instructional Materials that Guide Students in Genre Analysis[4]

[Excerpt 4A, referred to below, is located at the end of Appendix C.]

✍④ **Exercise C1.** As you browse through Excerpt 4A, consider the following questions:

(a) What organizational and writing conventions do you recognize from the Methods section? Use notations to underscore capitalization, numerical formats, and the use of parentheses.

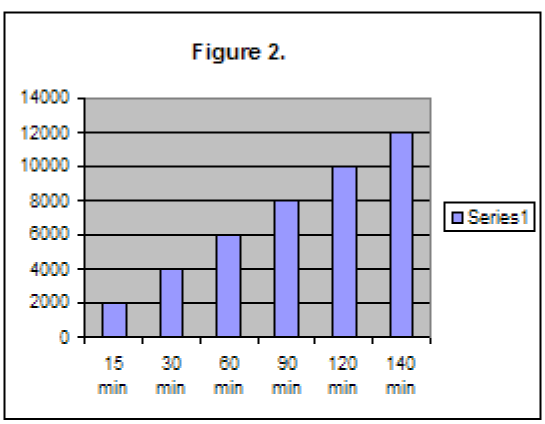
(b) What scientific conventions do you notice in the table and figure?

(c) Which sentences or paragraphs belong in the Results section, which belong in the Discussion section? How does the language help you differentiate between the two?

(d) What did the authors do to make their writing concise, as expected by an expert audience?

✍④ **Exercise C2.** Even though the authors of Excerpt 4A combined the Results and Discussion (R&D) into a single section, can you find 5 sentences that are clearly results and 5 sentences that are clearly discussion? Which approach to the combined section best characterizes this excerpt: Blocked R&D, Iterative R&D, or Integrated R&D?

✍④ **Exercise C3.** What scientific conventions do you notice in the bar graph in Excerpt 4A? Using your observations, examine the bar graph below. List at least 5 features of the bar graph that do not follow standard practices. (We have identified at least 6 unconventional features in the bar graph below.)



④ **Exercise C4.** Reexamine Table 2 in Excerpt 4A. What scientific conventions are most notable in that table? Compare the table in Excerpt 4A with the table below (adapted from the same article as Excerpt 4A). The table below lists the correlation coefficients ($R^2$), the coefficient of variation (CV), and the relative recovery (RR) of the aldehydes analyzed in Excerpt 4A. Based on your comparison, use word processing software to reconstruct the table below in a format more appropriate for a journal article (and expert audience).

| | $R^2$ | CV | RR |
|---|---|---|---|
| 2-Methylpropanal | .9639 | 4.7% | 110% |
| 2-Methylbutanal | .9723 | 4.6% | 104% |
| 3-Methylbutanal | .9706 | 4.0% | 109% |
| Pentanal | .9951 | 3.9% | 114% |
| Hexanal | .9925 | 4.3% | 103% |
| Furfural | .9892 | 5.1% | 99% |
| Methional | .9983 | 2.4% | 90% |
| Phenylacetaldehyde | .9839 | 5.3% | 98% |
| (E)-2-Nonenal | .9944 | 8.0% | 89% |

## Excerpt 4A

Adapted from Vesely, P.; Lusk, L.; Basarova, G.; Seabrooks, J.; Ryder, D. Analysis of Aldehydes in Beer Using Solid-Phase Microextraction with On-Fiber Derivatization and Gas Chromatography/Mass Spectrometry. *J. Agric. Food Chem.* **2003,** *51*, 6941-6944.

### Results and Discussion

**Identification**. Most aldehydes, except formaldehyde, form two geometrical isomers of the derivatives that are represented by two peaks in the chromatogram. Identification of the carbonyl PFBOA derivatives was performed by mass spectrometry using electron impact ionization running in the scan mode. It was confirmed that fragment *m*/*z* 181 was the main fragment of all analyzed aldehydes (*6*). Figure 1 shows as an example the mass spectrum of the PFBOA derivative of methional. To increase the selectivity of the method, all aldehyde analyses were run in the single-ion monitoring (SIM) mode with monitoring for *m*/*z* 181.

Beer was also analyzed by gas chromatography/mass spectrometry (GC/MS) without being derivatized by PFBOA in order to ensure that there were no other sources of *m*/*z*181 besides the derivatization agent.

**Optimization of Derivatization Procedure.** Different parameters that impact the partition of aldehydes between the headspace and the solution, such as derivatization time, temperature, and ionic strength, were tested. The effect of pH was not examined because it was previously shown that the natural pH of beer, 4.5, is sufficiently low for the derivatization reaction (*6*). Therefore, the pH of standard mixtures was adjusted to 4.5 using 0.1% phosphoric acid. Since methional appeared to be the most problematic aldehyde to detect, optimization was carried out in a 5% ethanol (pH 4.5) solution spiked with 5 ppb of methional.

The effect of temperature on the extraction of methional from ethanol solution and its derivatization on a PFBOA-loaded fiber was examined for 35 and 50 Â°C (Figure 2). Increasing the extraction temperature caused an increase in the peak area of the derivatized methional. On the basis of this result, subsequent derivatizations were conducted at 50 Â°C.

The optimal derivatization time was also tested. The ethanol solution spiked with 5 ppb of methional was exposed for 15, 30, 60, 90, and 120 min at 50 Â°C. It was determined that the time to reach equilibrium between stationary phase and sample headspace was 90 min (Figure 3). A derivatization time of 60 min at 50 Â°C appeared to be a good compromise between the time of reaction and analyte response.

Figure 4 shows that addition of salt (2 g of NaCl in 10 mL of methional solution) did not have any effect on the extraction and derivatization procedure (60 min, 50 Â°C).

**Calibration.** For the calibration purposes, the sum of the peak areas of the two geometrical isomers was used for calculations. A six-point calibration curve for nine carbonyl compounds was measured. The calibration range was 0.1-50 ppb, except for (*E*)-2-nonenal, where the calibration range was 0.01-5 ppb. The matrix used for calibration solutions was 5% ethanol solution, pH 4.5. Correlation coefficient ($R^2$) values indicate that this method can be used for analysis of aldehydes in a wide range of concentrations (Table 1).

**Method Validation.** Reproducibility of the method was determined by repeatedly analyzing one beer sample 10 times. Table 1 shows that the method provides very good reproducibility, with coefficients of variations for monitored aldehydes below

5.5%, except for (*E*)-2-nonenal. The higher coefficient of variation for (*E*)-2-nonenal may be due to extremely low levels of this aldehyde in the analyzed beer.

**Beer Analysis.** Nine aldehydes were detected in analyzed beer (Figure 5). The resolution of two peaks, representing two geometrical isomers of each aldehyde, was good, except for furfural, where the first peak was clustered with a peak of an uncharacterized compound.

The aldehydes 2-methylpropanal, 2-methylbutanal, 3-methylbutanal, methional, and phenylacetaldehyde are so-called Strecker aldehydes, formed as a result of a reaction between dicarbonyl products of the Amadori pathway and amino acids, having one less carbon atom than the amino acid (*1*). According to Schieberle and Komarek (*8*), the increase of Strecker aldehydes and some esters might play a central role in flavor changes during beer aging. The same authors exclude (*E*)-2-nonenal, a degradation product of linoleic acid, as a key contributor to the stale flavor of beer. Other aldehydes related to the autoxidation of linoleic acid are pentanal and hexanal (*1*). Furfural, a product of the Maillard reaction, is a known heat exposure indicator that does not impact beer flavor due to its high flavor threshold (*9*).

During long-term storage at elevated temperatures, American-style beers develop a stale flavor (*10*). Analyzed beer samples were stored at 30 Â°C for 4, 8, and 12 weeks. Levels of all aldehydes increased during beer storage compared to the control sample (Table 2). Although the increase after 12 weeks at 30 Â°C was significant (16-fold increase for furfural, 7-fold increase for 2-methylpropanal), none of the analyzed aldehydes exceeded their flavor threshold in beer (*11*). However, it is probable that additive or synergistic effects take place when aldehydes contribute to the stale flavor of aged beer.

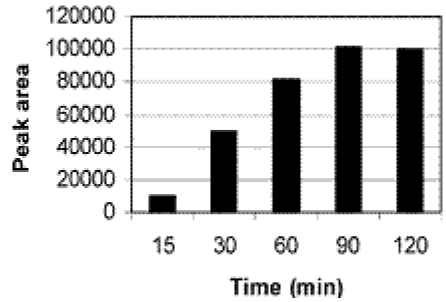



**Figure 3**. Plot of time of derivatization versus detector response area of PFBOA derivative of methional.

**Table 2. Aldehyde level changes (ppb) in beer during storage at 30 ℜ°C and 0 ℜ°C.**

| | 0 ℜ°C | 30 ℜ°C | | | |
|---|---|---|---|---|---|
| | 12 w | 4 w | 8 w | 12 w | FT[a] |
| 2-methylpropanal | 6.1 | 20 | 30.6 | 42.4 | 1000 |
| 2-methylbutanal | 1.8 | 3.1 | 4.2 | 5.2 | 1250 |
| 3-methylbutanal | 12.2 | 17.2 | 20.7 | 24.4 | 600 |
| pentanal | 0.3 | 0.6 | 0.7 | 0.8 | 500 |
| hexanal | 1 | 1.8 | 20.1 | 2.5 | 350 |
| furfural | 28.8 | 202.8 | 362 | 458.3 | 150000 |
| methional | 2.8 | 3.6 | 4.1 | 4.6 | 250 |
| phenylacetaldehyde | 6.6 | 9.9 | 10.1 | 12.7 | 1600 |
| (E)-2-nonenal | 0.01 | 0.02 | 0.02 | 0.03 | 0.11 |

[a]Flavor threshold in American-style beer (*11*).

# Appendix D

Examples of Reflective Writing Tasks[5]

**Exercise D1.** Reflect on what you have learned about writing a Methods section for a journal article. Select one of the reflection questions below and write a thoughtful and thorough response.

(a) Reflect on the differences between the ways in which methods are reported in lab manuals, lab reports, and journal articles.

- What are the predominant differences between the ways in which methods are reported in lab manuals, lab reports, and journal articles?
- Why do you think that the formats are so different?

(b) Reflect on the numerous scientific writing conventions that are typical of a Methods section in a journal article.

- Which writing conventions are relatively new to you?
- Which writing conventions have you used before?
- Which writing conventions do you have to make an effort to remember?
- Why do you think expert readers and writers in chemistry take these conventions so seriously?

(c) Reflect on the numerous excerpts that you have read in this chapter. Excerpts 3A through 3X come from different journals and report on different types of chemical research, but they have all been written for expert audiences.

- What features do the excerpts have in common? Give specific examples in your response.
- What features of this professional writing are most impressive to you?
- What aspects of this writing do you think will be easiest to learn to use? Hardest to learn to use?
- How does reading the chemical literature help developing writers?

(d) Reflect on the ways in which tense and voice are used in a Methods section.

- What rules have you created for yourself to remember when to use active voice and when to use passive voice in a Methods section?
- What rules have you created for yourself to remember when to use present and past tense in a Methods section?
- Why is it important to use tense and voice correctly? In what ways can improper usage cause miscommunication with your readers?

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[2] Readers interested in piloting in 2005-2006 should contact author Fredricka Stoller at <Fredricka.Stoller@nau.edu>.

[3] Taken from an instructional unit on the Methods section of a journal article.

[4] Exercises taken from a chapter on the Results section of a journal article.

[5] Tasks taken from a chapter on the Methods section of a journal article.

## Contact Information

Fredricka L. Stoller
Northern Arizona University
**Telephone:** 928-523-6272
**Fax:** 928-523-7074
**Email:** fredricka.stoller@nau.edu