# Developing Students' Multi-Modal and Transferable Writing Skills in Introductory General Chemistry

SUSAN GREEN, ZORNITSA KEREMIDCHIEVA, HEIDI ZIMMERMAN, AMY RICE, LEAH WITUS, MARC RODWOGIN, AND RUTH PARDINI

Undergraduate chemistry programs are increasingly benefitting from the inclusion of writing pedagogy. Writing is more than a mode for relaying information in chemistry. To begin with, a growing literature demonstrates its value as an active learning experience that helps develop students' grasp of chemical concepts, the research process, and the communal dynamics of the profession (Shires, 1991; Sunderwirth, 1993; Bressette & Breton, 2001; Vázquez, et al., 2001). Despite being listed as a discrete skill in the most recent guidelines on undergraduate education by the American Chemical Society (ACS), writing can be a powerful tool for cultivating all the other core competencies of rigorous undergraduate programs: problem-solving skills, chemical literature skills, laboratory safety skills, team skills, and ethics. Furthermore, writing in chemistry can be viewed as its own form of content with concepts, norms, and strategies that students may not be able to pick up in other writing-intensive courses across the undergraduate curriculum (ACS, 2015). Quality undergraduate training in chemistry, therefore, requires an intentional and systematic approach to developing students' facility with the disciplinary norms, compositional processes, genres, and contexts for writing in the field.

As is often the case, however, putting theory into practice is often a challenge unless instructional strategies and materials, faculty development and preparation, and structural arrangements become intentionally aligned. We teach at Macalester, a highly selective small liberal arts college located in Saint Paul, Minnesota, that enrolls a little over two thousand students. For years, our community's commitment to writing pedagogy had been expressed through a general education writing requirement to which, unfortunately, the natural sciences rarely contributed. In 2014, the faculty voted in a new three-tier writing across the curriculum program and, with the support of an institutional grant dedicated to promoting multi-modal writing pedagogy from the Andrew W. Mellon Foundation, the college appointed a faculty member as its first writing director. The collective aspiration behind the new writing program was to build a college-wide culture of writing, of which the natural science division would need to become an integral part.

In this article we share our effort to integrate and synchronize the two approaches—"writing to learn" chemistry and "learning to write" in chemistry—in Macalester College's first-semester, introductory, multi-section course CHEM 111: General Chemistry I: Structure and Equilibrium. Collectively, our course typically enrolls around 135 students each fall (139 in 2015, 134 in 2016), the large majority of whom are first-year students even if they often arrive with AP, IB, or other credit that may give them sophomore standing. In the fall of 2015, 14% of our students were juniors or seniors. The following year, that percentage was 8%. Due, in part, to a college-wide distribution requirement for students to take at least eight credits in the natural sciences, our course enrollment typically matches the demographic diversity of the campus with 59% women, 41% men, 11% under-represented ethnic minorities, and around 15% international students.

As chemistry instructors, our decision to collaborate with the college writing program was motivated by two sets of considerations: one was substantive, the other procedural. Substantively, we were first guided by our general sense of dissatisfaction with the quality of students' work in previous semesters. Similar to the experience of chemistry faculty at other schools (Stout, 2011), we were concerned that since students often seemed to demonstrate only superficial understanding of the material, the presentation of their lab results was often confusing and, therefore, difficult to grade. Second, the majority of our students take General Chemistry I during their first semester of college; therefore, we bear a responsibility to use the class as a gateway into the college experience writ large. Most of the students in the class do not go on to become chemistry majors, so this class could be useful in equipping them with general writing skills that would transfer to other fields, both in the sciences and beyond.

Procedurally, we were facing a set of challenges that are common to chemistry programs. First, our instructors have diverse backgrounds, different kinds of expertise and levels of experience. Of the four instructors in 2015, three had PhDs, and one had a BA; two had been teaching for over a decade, and two were teaching for the very first time. Our setup for General Chemistry is a typical one, with students enrolled in a lecture course and a laboratory section. Like many other schools, we offer multiple lecture and lab sections of this introductory course. Students from any of the lecture sections may take any of the laboratory sections. Laboratory sections in the 2015–2016 academic year were taught by any one of four instructors, only two of whom also taught a lecture section. Hence, we were looking for a way to synchronize and streamline the approach of all the different teachers so that students would be able to expect equivalent experiences regardless of their lecture or laboratory section assignment. We also aimed to develop an approach to writing instruction that was sensitive to the time pressures, work load, and varying levels of preparation of the instructors and that would provide them with the tools and confidence needed to support students' writing development.

Second, we faced a situational concern. Space constraints due to enrollment pressures called for reorganizing the lab component of the class. During departmental planning meetings for the 2015–2016 academic year, we realized that we did not have sufficient space for each lab section to meet in a designated laboratory every week. Thus, we decided to move to a schedule in which each lab section would be in the laboratory spaces only every other week; these were our "wet lab" sessions. A major concern with this change was that students would not be as well prepared for more advanced science courses. This meant that on alternating weeks, students would have to be presented with other meaningful learning activities in regular classrooms. We called these regular classroom sessions "dry labs" to highlight their hands-on, experiential approach to learning.

Dedicating these dry lab sessions to writing instruction appeared to be our best strategy for responding to our challenges and bringing our curriculum into better alignment with the ACS's most recent statement of learning outcomes for chemical education. We noted in particular that writing and communication skills were integral to practically all five of the listed skills. Thus, dedicating more time to students' writing would not come at the expense of content. On the contrary, our bet was that if students were led to pay closer attention to the way in which they generated, represented, and interpreted data in writing, they would develop a deeper understanding of the concepts and experiences they gained during their lab experiments. Like others (Alaimo et al., 2009; Stoller et al., 2005), we considered the points of synergy between the teaching objectives of the Chemistry Department and our campus-wide writing program. To help us formulate a theoretically informed and evidence-based approach to writing pedagogy, we collaborated with Macalester's Director of Writing, Zornitsa Keremidchieva. The Mellon grant allowed us to also enlist the help of the Postdoctoral Fellow in Writing Instruction, Heidi Zimmerman, who assisted us in crafting our teaching strategies and materials, coordinated our assessment protocols, and created a semi-ethnographic record of the students' performance and questions during our sessions that allowed us later to review and fine-tune our approach. Together, our efforts built up to a model that we believe would be useful to other natural science programs seeking more systematic and fine-tuned ways of implementing writing pedagogy.

## Theoretical Framework for Writing in Introductory Chemistry

In designing the writing dry labs and assignments in our introductory chemistry class, we set the following pedagogical goals: (1) to provide students with active learning experiences that would boost their understanding of chemistry concepts and theoretical frameworks; (2) to introduce students to the genres and conventions of writing and communication that are important for careers in chemistry; and (3) to prepare students for college-level writing and learning more generally by introducing them to habits, vocabularies, and processes that are likely to increase their ability to participate and learn in classes across the curriculum.

Our approach in pursuing these goals took advantage of the existing professional literature clarifying the stylistic norms of writing in chemistry (Robinson et al., 2008) and incorporated established best practices in chemistry pedagogy for scaffolding the writing process by intentionally sequencing assignments and activities to support discovery, writing, and revision (Walker & Sampson, 2013; Van Bramer & Bastin, 2013; Deiner, Newsome & Samaroo, 2012). However, two considerations suggested that mainstay practices of direct instruction in the generic norms of lab reports might be insufficient for meeting the larger purposes of writing in chemistry as well as across the curriculum. First, scholarship in writing studies and the field of teaching and learning has revealed that writing is a complex skill, better defined as an assemblage of skills: linguistic, cognitive, behavioral, social, and affective (Moore, 2012; Adler-Kassner & Wardle, 2015). Its development, therefore, invariably requires sustained, reiterative support that transfers beyond any single classroom experience (Melzer, 2014). As the research behind the National Research Council Committee on Developments in the Science of Learning's statement *How People Learn: Bridging Research and Practice* also suggests, classroom instruction in any content area, such as chemistry or writing, is most impactful when it is strategically and consistently designed to foster knowledge "transfer," that is, when it is designed to help students gain the ability to connect the dots between, and benefit cumulatively from, their divergent learning experiences (Donovan et al., 1999). The question of transfer is particularly pertinent to our work because in the course of their careers, both our STEM majors and non-majors will have to write in a variety of genres and for different purposes.

While as chemistry instructors we are still getting better at staging the writing process to help students produce effective laboratory reports, the "teaching for transfer" approach calls us to consider how we can develop students' ability to eventually take on the task of scaffolding their own inquiry. "Put briefly, the question asks how we can support students' transfer of knowledge and practice in writing; that is, how we can help students develop writing knowledge and practices that they can draw upon, use, and repurpose for new writing tasks in new settings" (Yancey, Robertson & Taczac, 2014, p. 2). As we strive to bring coherence and alignment between the courses in our curricula, we should also focus on how our pedagogical practices encourage or deter students from bridging prior and new learning experiences. Teaching for transfer impels us to consider that the success of writing pedagogy in chemistry should ideally be evidenced not only by the production of clear and accurate research reports as part of discrete course assignments, but by the ability of students to identify and adapt to the generic features, target audiences, and purposes of new writing situations in their careers in chemistry and beyond. Such emphasis on the transferability of writing strategies is of particular importance to first-year students whose further academic success will depend on their ability to adapt to the epistemic diversity of the various STEM fields as well as the rest of academia.

Second, chemistry writing is multi-modal; it requires the development of integrated typographic and visual, humanistic and quantitative literacies. Recent developments in composition theory draw attention to the complex competencies involved in multi-modal communication. Multi-modal texts are characterized by "the mixed logics brought together through the combination of modes (such as images, text, color, etc.)" (Lauer, 2009, p. 227), and they routinely call on their authors to make strategic judgments about the comparative communicative effect of using one mode versus another. In chemistry, visualizations in the form of tables and graphs are often surrounded by linear text. Yet, the composing and design processes and visual grammar involved in these two forms of inscription are not necessarily analogous or interchangeable even if they both serve as tools of meaning-making and communication. Put simply, "there is little reason to argue that the visual and the verbal are the same, are read or composed in the same way" (George, 2014, p. 213).

Chemistry pedagogy needs to grasp these distinctions while all the while highlighting the transferability of these modes of communication. It also needs to acknowledge the diverse cognitive and rhetorical purposes and modes for science writing. We don't use writing only to *communicate* findings, but also to *record* observations, to *organize* our data collection and workflow, to *visualize* patterns and relationships, and to *clarify* our thinking. In other words, attending to the diverse ways in which various writing practices support our work matters for preparing students for both the technical and social rigors of the STEM professions. As the teaching-for-transfer and the multimodal writing pedagogy movements are relatively recent developments, we could not find ready-to-use curricular models applicable to a disciplinary and institutional context like ours. We committed, therefore, to putting together a coherent curriculum that was simultaneously informed by the theoretical insights from the field of writing studies and articulated to the unique demands of science pedagogy. As importantly, we learned how our own collaborative writing process—as a form of faculty development and team-building—made a difference in creating the conditions for institutional implementation and cultural change. The following section offers a detailed account of our experience.

## Curricular Implementation

In our own working process, we began by drafting our learning goals, and from those we reverse-engineered the activities and materials that would be needed. During our meetings, the writing director served as our main scribe, prompting, taking down, and organizing everyone's comments and continuously calling on us to clarify any concepts, terminology, or ideas that could be unfamiliar to a lay audience. In collaboration with the post-doctoral fellow, we would then further flesh out and design the written teaching materials. These meetings proved crucial not only for producing the elements of our curriculum, but also for calibrating our shared expectations and aspirations for students, for learning from each other's experience, and for building our collective philosophy and conceptual vocabulary with respect to writing pedagogy. On that last note, we admit that learning for us turned out to be just as powerful as unlearning, as our closer engagement with the writing director helped clear out a number of mythologies and misconceptions about writing that for a long time had been holding us back from engaging with the writing program.

Like many other introductory chemistry courses, we made lab reports the central writing projects in our class. However, our approach was distinctive because we sequenced and scaffolded the course assignments and activities in a way that aimed to teach students' composition and scientific discovery *as intertwined, mutually reinforcing processes*. Specifically, we staged the writing of the chemistry lab reports through inquiry-driven steps instead of generic parts, and in each step we connected chemistry discovery skills (making observations, doing and understanding calculations with data, and interpreting results) with corresponding science communication competencies (recording lab activities in lab notebooks, using Excel or other spreadsheet software to organize data, creating data visualizations, interpreting and explaining data with consideration of audience, genre conventions, and purpose). In other words, we sequenced our writing activities in an order that reflected not the organization of the final lab reports (i.e., introduction, observations and procedure, data, calculations, results, discussion, and conclusion), but rather the steps of grounded inquiry (observation, data organization, and interpretation) with specific attention given to the way various modes of writing enabled each step to unfold. As is common for introductory chemistry classes, we did not require students to conduct literature reviews. Instead, we provided them with research questions to guide their observations and interpretations. Thus, our approach reflected the notion that "doing chemistry experiments, thinking like a chemist, and writing like a chemist are inseparable" (Alaimo et al., 2009, p. 19).

In total, the students completed three full lab reports. For each of these, they began by writing down observations in their lab notebooks, then moved on to using their notes to help them make any necessary calculations and process, organize, and make sense of the data in table and graph forms keeping in mind the research question that we had posed for them. Then they wrote explanations of the data that were presented in their figures, composed the conclusion, and, finally, wrote the introduction sections of their lab reports. Each of these stages of writing simultaneously made evident and impelled the students' continuous engagement with and understanding of the chemistry concepts. Each writing element (recording and describing observations, visually representing data in tables and graphs, and writing introductions and conclusions) was reiterated at least twice in the course of the semester. It was also scaffolded by requiring preliminary drafts, conducting interactive dry lab sessions that highlighted the principles behind the form, and involved rigorous in-class peer reviews. Not the least, we used teaching materials that we designed with the help of our writing director and post-doctoral fellow to specifically highlight the substantive and communicative dimensions of our activities. We are willing to make these materials available as supplemental information to this article.

The assignment sequencing, in-class activities, peer review sessions, and teaching materials were all informed by Yancey, Robertson, and Taczak's (2014, pp. 138–139) key suggestions for teaching transferable writing skills. Specifically, they encourage instructors to: (1) be explicit about the conventions of writing in a given discipline; (2) demonstrate, rather than explain, these conventions; (3) tap into students' existing knowledge; (4) teach writing as a composing process, rather than simply an end product; (5) teach reiteratively, reinforcing the concepts and practices of effective written communication across assignments and activities; and, finally, (6) help students develop metacognition, or thinking about their own learning, so that they recognize the role of strategies like sequencing assignments and peer review in their development as writers and learners.

To put these principles into practice, during our dry lab lessons instructors demonstrated effective chemistry communication and invited students to bring their existing knowledge to the table. We created a number of inquiry-based activities in which students worked with samples of graphs, tables, conclusions, and introductions and drew from their own expertise and experience to generate lists of criteria for what made the samples effective and accurate, or, conversely, difficult to read or understand. For example, one such lesson combined teaching students how to use a spreadsheet program (Excel, in our case) with teaching them how to create and write about data visualizations. After an activity in which students input data gathered during lab into Excel, instructors went over our "Graphs and Tables" handout. Then, in pairs, students examined a range of data tables that the lead instructor had created. The tables had a number of common issues we had seen in student work over the years—strange decisions about column width and row height, odd spacing and alignment of data, absent or confusing headings, labels, units, and titles, among others. From these samples, students generated lists of their own criteria for what constituted effective visualizations. When they returned to their own Excel sheets, they formatted their data into effective tables, created a graph from their data, and wrote short paragraphs explaining the visualizations.

On another occasion, the instructors distributed sample introductions from former chemistry students' honors theses. The instructors asked, "What makes these introductions strong?" In pairs or small groups, students read the introductions and generated lists of criteria for effective introductions, which were subsequently shared with the class on the whiteboard and compared to the criteria that the instructors had provided. Students then revised their own introductions during lab. Through these activities, students internalized not only the concepts that we were teaching but also criteria by which they could evaluate their own performance.

Such scaffolding activities required teaching materials that would successfully bridge students' in-class and out-of-class learning and understanding of both the chemistry and the communication concepts that we were trying to inculcate. We devoted significant effort to creating instructional materials that were explicit about the conventions of chemistry communication. For practiced science communicators, the norms of science writing are often so naturalized that it becomes difficult to anticipate and explain skills and stylistic conventions that are in fact entirely mysterious to novice student writers. We worked together to identify the specific competencies that enable chemists to produce effective lab reports. Our list included the ability to communicate visually in graphs and tables, use correct significant figures, explain data with well-organized and clear prose that fits logically into the overall report, use transitional language to guide readers through the findings, and create effective introductions and conclusions, among others. We then created a range of explanatory handouts to explicitly teach each of these communicative modes. These handouts did three things. First, they briefly defined a communicative mode (e.g., a graph, a data table, significant figures, or a lab report). For example, graphs were defined in the following manner:

> What is a graph? A graph is a tool for visually representing the relationship between two or more things. Although we use information about raw data to create graphs, graphs are not raw data. Graphs transform raw data, through a process of representation, into something that communicates.

The handouts then explained the connection between writing and scientific practice; for example, "Why do chemists use significant figures? Chemists use significant figures to communicate information about their measuring tools and the precision of their data." Third, each of our handouts included a detailed and specific discussion of the key principles that make for successful execution of the activity/object. General questions, such as "What makes a good graph/table/lab report/etc.?" were followed by a discussion of considerations ("Who is your audience and what is the purpose?")

and clearly explained criteria (e.g., clearly labeled axes, clear and succinct statement of purpose, clear transition and topic sentences, data explained logically in the context of the overall narrative of the report, etc.) for creating accurate, readable and effective graphs/tables/reports.

Along with these conceptual handouts, we created two checklists—one developmental and the other summative—which students could use as they worked on their lab reports. Both checklists aimed to support students' independent writing and revision. The developmental checklist was distributed to students in advance of the deadline for the rough drafts of their lab reports. Consistent with our broader strategy for sequencing the assignments, this checklist was arranged in a manner that encouraged students to write not from beginning to end, but in the order in which grounded inquiry unfolds. It encouraged students to begin with the category "Data" (which included items like "All raw data are included" and "Correct significant figures and correct units are used"), then prompted them to check the quality of the other steps in producing the report before finally ending with the "Introduction" section (which included criteria like "Answers the question 'What was the objective of the experiment?' in a single declarative sentence"). The summative checklist included the same sections (Data, Sample calculations, Observations and Procedure, Conclusion, Introduction), but it was re-sequenced to reflect the conventional organization of the final report (from introduction to conclusion).

A final, and crucial, strategy in scaffolding the writing process and promoting its transferability was the integration of regular peer-review sessions. We held structured peer-review sessions during our dry labs to help students master individual communicative competencies—specifically, graphs, tables, conclusions, and introductions—before putting together their final reports. The peer-review sessions included a handout explaining the purpose of peer review and detailing "best practices" for authors (e.g., "Bring to the workshop session your best possible draft and make sure you have enough copies for all the reviewers") and for reviewers (e.g., "Be a good listener. Take seriously the concerns of the writer and read his/her paper closely and carefully, noting any elements that slow you down or confuse you."). We also distributed worksheets with questions for the reviewers to respond to (e.g., "Did the author state the main purpose of the experiment in a single declarative sentence? Is it clearly stated and easy to find? Does it explain what the experiment is aiming to test, discover or replicate? Does it prepare you, as a reader, for what is to come? Jot down what you like about it and your suggestions for improvement"). Students were asked to talk over the entire worksheet after reading the drafts, and initial a contract confirming that they had done so. Time was provided during the lab for students to revise their work based on the peer review.

In sum, all of our instructional strategies were guided by the key notion that in order to teach students skills that would at once deepen their understanding of the course content and help them develop writing abilities that would transfer to their future college classes, instructors must teach writing reiteratively and in a manner that allows students to recognize that learning is a process. We regularly reinforced both the concepts of *chemistry* and of *communication*. Concepts such as *significant figures*, *readability*, *accuracy*, *genre*, *audience*, and *purpose* appeared across our handouts and instructors used them repeatedly to explain and support the activities. We aligned assignment descriptions, checklists, and rubrics so that they all contained the same vocabulary and requirements. We also aimed to help students develop metacognition, or "thinking about thinking." Rather than learning writing conventions by rote, students were regularly asked to think about the "why," "how," and "for whom" of communicative practice in the context of chemistry. We wanted them to recognize the conventions of chemistry communication not as arbitrary rules to be memorized, but as conventions that emerged in a specific context for specific communicative purposes. In this way, our aim was not simply to teach students a particular set of writing conventions, but to teach students how to learn writing conventions, which would set them up to succeed in future writing in chemistry as well as in their other courses and careers.

## Results

In evaluating our curricular revision, we were concerned with two questions: first, how it affected students' learning, and second, how it affected the labor and experience of teaching the lab component of the class. Though distinct, we felt that these two questions were related in practice as no curriculum can be sustainable unless both teachers and students see it as applicable and meaningful. Hence, in evaluating the changes that we made to our teaching strategies, we sought to gather rich, qualitative feedback. We interviewed the instructors. We surveyed the students and gave them opportunities to describe their experience in their own language. The post-doctoral writing fellow observed and generated field notes from multiple sections of all writing-specific dry lab sessions as a way to gather in-situ input. We also used the written work that students submitted as primary evidence for their learning. Based on these multiple sources of data, we were able to make the following observations.

First, with respect to our primary goal in revamping the curriculum, namely to provide students with active learning experiences that would boost their conceptual grasp of chemistry, we noted marked improvement in the level of work that students produced. This observation was derived from several sources of data. One source was the direct assessment of student work. Having developed a common grading rubric that calibrated our assessments across all sections, we noted two developments: one was a new-found consistency in student performance across sections despite the randomized method of enrollment as managed by the Registrar; the second one was a trend toward improved performance all around. While we could not perform an all-inclusive test comparing scores from all lab reports written before and after our intervention because both our rubric and the format of some of the experiments had changed, there was one lab that had remained essentially the same. The only change in the Chemical Equilibrium lab was the way the writing process was scaffolded. We had retained samples of lab reports from one section from the previous year, and we decided to re-score them using our new rubric. When we applied our new scoring rubric to the samples from 2014, the average score was 51.7%. In comparison, the average score for the same lab reports in the context of the new curriculum was 76.6% in 2015 and 79.2% in 2016. In other words, we witnessed around 25% gains in the substantive quality of student work. This transformation in the scores was consistent with the reports of the instructors, some of whom had been teaching these labs for years and had a solid basis for comparison. As one testified, "for years I had suffered through piles of mis-shapen tables, mismatched questions and observations, and inaccurate significant figures. And now suddenly I am looking at lab reports in which it is hard to find a single misplaced figure!"

This time around, both in class, as reflected in the post-doc's field notes and in the written work, as reflected in the peer-review worksheets, students began to ask better, more conceptual, questions, suggesting that the writing assignments were helping them understand the material in more sophisticated ways. The instructors noted that students were now regularly making subtle observations, which even our most advanced students had not been making before we instituted the new teaching strategies. To take the Chemical Equilibrium experiment, for example, in previous years a very good lab section might have as many as 75% of students conducting the critical calculations properly. In other words up to 25% of students would fail to do the central calculation of the experiment correctly, thus failing to understand the central question of that lab experience. Using the current writing-based curriculum, it is unusual to have more than 10% of the students in any given lab section fail this task, suggesting that the added engagement with the material that comes with writing up the experiment increases the students' understanding of the chemical concepts. When asked which of the dry labs was the most helpful in 2015, a student commented: "Chemical Equilibrium because it is challenging, but once I finished the lab report, I can understand the concepts really well." Other students testified that the dry labs "definitely helped with technical writing skills and overall expansion of ideas/concepts" and that "the lab reports forced me to really consider the results of the experiment in depth."

The student comments that we received in fall 2015 and fall 2016 further supported our impression that students were grasping the connection between their writing and learning in chemistry. Customarily, we survey our students at the end of the semester. These surveys are an important opportunity for students to provide anonymous feedback on their experience. In General Chemistry, we use a common questionnaire in all laboratory sections. It is handed out by the instructors who then exit the room, leaving a student in charge to collect all the forms and submit them to a designated campus administrator. Faculty do not receive these forms back until all grades are submitted. The results from each section are then aggregated into common data for the course, thus allowing us to track both individual instructors' performance and the essential features of the curriculum.

Before implementing the writing component of the class, students had often reported that even after completing their lab reports, they didn't understand what they had done in the lab or why they had done it. Going as far back as 2012, they had been testifying that they did not find "much correlation between the labs and the class" if they commented on the lab component at all. Starting with fall 2015, their summative assessment and comments changed dramatically. In that semester, a record number of students (67% of the 139 students enrolled in the class) responded to questions about their lab experiences. Their summative assessment was quite positive with 48.4% agreeing or strongly agreeing that the wet labs fit well with the concepts they learned in the lecture portion of the course (8.6% strongly disagreed), and 61.3% agreeing or strongly agreeing that the dry labs had helped their conceptual understanding (only 2.2% strongly disagreed). In Fall 2016, in response to the same questions, 48.5% of students agreed or strongly agreed that their wet labs helped them understand the material (3% strongly disagreed), while the number of students who testified that the dry labs helped their conceptual understanding climbed to 71.2% (0% strongly disagreed).

The written comments provided us with rich insights into the way students construed the connection between the writing assignments and their learning in chemistry. Specifically students remarked that: (1) the deliberative character of the writing workshops deepened their understanding of the lab procedures: "Being able to comment on other people's work and have them comment on mine really helped me to understand what I was doing right and wrong in lab;" "[the dry labs] facilitated calculations and through discussion, they facilitated my understanding of the wet lab results"; (2) they promoted a sense of community and teamwork: "they helped me understand because I felt like the dry labs were less of a stressful environment and it was easier to ask questions," and "it was nice to have a concentrated group of people who were all working on the same thing as you to help with questions and clarity"; and (3) they deepened students' grasp of scientific inquiry and the role of writing in it: "they gave me more criteria to meet in writing a good lab report and allowed me to think critically about the data we had gathered," and "more conceptual than physical, helps wrap the brain around what we are actually doing." To sum up the intellectual impact of the writing component of the class, one student noted that the dry labs "helped develop [his/her] thinking in the context of scientific writing and research." The writing process, in other words, helped put the scientific process firmly in place.

Similarly, we observed significant improvements with respect to our second goal of cultivating our students' competency with the conventions of science writing and their general communication skills. Our rubric scored both substantive and stylistic elements even as it emphasized the constitutive relation between them. Consistent with past trends, many of our students reported that they had had little to no experience with writing lab reports prior to our course. However, this time the written work that the students submitted was markedly superior to what we had seen in previous years, as gauged both by the instructors' reports and the re-scoring of past samples. As one instructor observed, echoing the comments of others, after the changes were implemented the lab reports became "more complete"; they captured more accurately and meaningfully the experimental experience, and they didn't exhibit a number of the endemic problems the instructors had been fighting for years, such as run-on sentences, missing data and calculations, strange formatting, and other features that were likely the result of last minute, rushed writing.

Students echoed the instructors' perception. In 2015, about half (48.4%) of the students reported that the writing portion of the course increased their comfort with writing (only 3% strongly disagreed). In the fall of 2016, despite some turnover in faculty, the scores only improved, suggesting that the teaching materials and format that we had developed were the critical factor shaping the student experience. This time around 64% agreed or strongly agreed that the dry labs improved their overall writing skills (only 2% strongly disagreed). Students also appeared to appreciate receiving instruction on how to write the individual, including multi-modal, elements of their lab reports. When in the fall of 2016 we added additional questions with a three point scale of "very useful," "useful," or "not useful at all" to survey their assessment of the dry lab exercises devoted to various aspects of the lab reports, we found overwhelmingly positive responses (very useful or useful) to the key instructional activities related to writing: 95% for formatting graphs and tables, 89% for using significant figures, 95% for readability of tables and graphs, 89% for conclusions, and 94% for introductions.

When asked to comment on how the dry labs impacted their writing skills, students highlighted the following aspects: (1) the value of developing genre awareness: "I had never written a full lab report before, so it was very helpful in instructing me in how to write a proper lab report," and "it provided a contrast of how a scientific article should be written in comparison to my social science class"; (2) an appreciation for the role of practice in writing development: "writing practice always helps," and "initially I was uncomfortable with how I handled lab reports because I felt as though they were pretty weak but as the semester continued, I became much more comfortable writing and reviewing my own lab"; (3) getting in the habit of seeking and using writing-related resources: "the checklist and peer review helped me writing lab reports," and "I guess it helped me become more vigilant with the standards written on the rubric"; and (4) understanding the value of peer review: "peer review helped me come up with more things to write," and "the peer reviews helped to see how other people were writing their lab report." To the extent that the writing transfer literature emphasizes the importance of developing students' meta-cognitive skills, we find such comments encouraging as they appear to demonstrate the development of a reflexive stance, active strategies, and a vocabulary about writing that could be applicable beyond our course.

Given CHEM 111's position as a course that students tend to take in their first semester of college, we felt responsible for helping students develop writing skills and habits that they would transfer constructively into their subsequent courses in chemistry and beyond. The feedback and assessment evidence we collected suggests that we are on the right track with respect to this third goal as well. We followed up with those students who continued on into the next course, CHEM 112: General Chemistry II, in the spring semester and discovered that they had both retained and continued to build on the writing skills they developed in CHEM 111. In the 2016–17 school year, 70% of the students who completed CHEM 111 in the fall then moved on to CHEM 112 in the spring semester. We tracked these students' performance and found that the skills they had gained in the lower level class held steady in the spring with an average gain in scores of 2%. We find that result to be encouraging because CHEM 112 requires students to write lab reports but does not explicitly scaffold or teach writing.

Finally, even if it highlighted the significant benefits of teaching with writing in chemistry, our model demonstrated that all instructors do not need to be trained writing pedagogues to be able to implement a writing curriculum and do so with consistency across multiple sections. None of the instructors had substantial previous experience in teaching writing. Neither did they need to share a common background. The teaching materials and lesson plans that we developed with the help of the college writing director and the Mellon Post-Doctoral Fellow in Writing Instruction (Green et al., 2016a,b) were robust enough to make it possible for students to have a similar experience regardless of instructor and for new instructors to subsequently pick up the baton and carry the program forward. The student work and the in-class observation notes that we collected in fall 2015 from all sections suggested that the new curriculum indeed enhanced the cohesion of our program. The same assessment, conducted the following fall by instructors, two of whom were new to the department, reaffirmed this view. Not the least, the common curriculum also ameliorated some of the inequities in the labor of grading and providing feedback and guidance to students that we had been concerned about. The written handouts and checklists anticipated many common questions and issues. And with a common rubric that was clearly aligned with our teaching strategies and materials, grading became much easier, faster, and more transparent, allowing the instructors to devote more time to substantive rather than procedural interactions with students.

In effect, the common curriculum also became a valuable professional development tool, which helped bring consistency and raise the standards for teaching in all sections. The conditions for skills transfer, apparently, did not benefit the students alone. Following our curricular implementation, in the fall of 2016 we shared our experience with the rest of the campus community with an hour-long presentation at Macalester's Jan Serie Center for Scholarship and Teaching. A year later, as the news of our revisions spread across campus and other faculty began to notice the effects of the training that we provided in their own students, a core group of colleagues from the natural science division gathered for a semester-long Faculty Learning Community on Science Communication supported by our writing director and our Mellon grant. There our approach was once again examined closely with an eye toward replicating it and modifying it in service of other campus programs and goals, with special consideration for its potential for increasing the retention of historically under-represented students in the sciences. We will continue to track our students' performance and share our experience with our colleagues in the interest of building a college-wide culture of teaching with writing.

The most important lesson we have taken away from this entire experience, however, is not derived from any one set of assessment numbers. Direct evidence of student learning is certainly essential in driving forward curricular innovation. But it is not sufficient. A collaborative and responsive culture of teaching and learning is sustained by continuous composition and reflection. What brought us together as a team was in fact the writing process itself. As we first gathered in a room with a sense of urgency but only a vague idea of the possible paths forward, with the support of the writing director we began to draft statements about what motivated us to come together and what we wished to accomplish. And as the words settled on the shared screen, our goals and values started to take shape along with our process and strategies. This same composing process then carried us through the task of devising our teaching materials. The fact that our writing director and the post-doctoral fellow in writing instruction had no background in chemistry only helped us as they continuously prompted us to make our assumptions visible to them and to ourselves, just as we would have to make them clear to our students. In this sense, if we have one piece of wisdom to share with others who might be interested in embarking on some form of curricular reform, it is to carry out the process in writing and through writing, with diversity among members of the team, and with full view of the accumulated knowledge that composition studies has to offer.

## References


Adler-Kassner, L., & Wardle, E. (Eds.). (2015). *Naming what we know: Threshold concepts of writing studies*. Logan, UT: Utah State University Press.

Alaimo, P. J., Langenhan, J. M., & Nichols, L. (2009). Eliminating lab reports: A rhetorical approach for teaching the scientific paper in sophomore organic chemistry. *The WAC Journal, 20*, 17–32.

American Chemical Society, Committee on Professional Training. (2015). Undergraduate professional education in chemistry: ACS guidelines and evaluation procedures for bachelors' degree programs. Retrieved May 18, 2015, from https://www.acs.org/content/dam/acsorg/about/governance/committees/training/2015-acs-guidelines-for-bachelors-degree-programs.pdf

Bressette, A. R., & Breton, G. W. (2001). Using writing to enhance the undergraduate research experience. *Journal of Chemical Education, 78*, 1626–1627.

Deiner, L. J., Newsome, D., & Samaroo, D. (2012). Directed self-inquiry: A scaffold for teaching laboratory report writing. *Journal of Chemical Education, 89*, 1511–1514.

Donovan, M. S., Bransford, J. D., & Pellegrino, J. W. (Eds.). (1999). *How people learn: Bridging research and practice*. Washington, DC: National Academy Press.

George, D. (2014). From analysis to design: Visual communication in the teaching of writing. In C. Lutkewitte (Ed.), *Multimodal Composition: A Critical Sourcebook* (pp. 211–232). Boston, MA: Bedford/St. Martin's.

Green, S., Keremidchieva, Z., Rice, A., Rodwogin, M., Pardini, R., Witus, L. & Zimmerman, H. (2016a). *Laboratory manual, Chemistry 111*. St. Paul, MN: Macalester College.

Green, S., Keremidchieva, Z., Rice, A., Rodwogin, M., Pardini, R., Witus, L. & Zimmerman, H. (2016b). *Chemistry 111 instructor manual*. St. Paul, MN: Macalester College.

Lauer, C. (2009). Contending with terms: "Multimodal" and "multimedia" in the academic and public spheres. *Computers and Composition, 26*, 225–239.

Melzer, D. (2014). The connected curriculum: Designing a vertical transfer writing curriculum. *The WAC Journal, 25*, 78–91.

Moore, J. (2012). Mapping the questions: The state of writing-related transfer research. *Composition Forum, 26*, Retrieved July 7, 2015, from http://compositionforum.com/issue/26/map-questions-transfer-research.php

National Research Council Committee on Developments in the Science of Learning. (1999). *How people learn: Bridging research and practice*. Washington, DC: National Academy Press.

Robinson, M. S., Stoller, F. L., & Jones, J. K. (2008). Using the ACS journals search to validate assumptions about writing in chemistry and improve chemistry writing instruction. *Journal of Chemical Education, 85*, 650–654.

Shires, N. P. (1991). Teaching writing in college chemistry: A practical bibliography, 1980–1990. *Journal of Chemical Education, 68*, 494–495.

Stoller, L. F., Jones, J. K., Costanza-Robinson, M. S., & Robinson, M. S. (2005). Demystifying disciplinary writing: A case study in the writing of chemistry. *Across the Disciplines, 2*. Retrieved June 3, 2015, from https://wac.colostate.edu/atd/lds/stoller.cfm

Stout, Roland P. (2011, June 27). "It's a shame to put such wonderful thoughts in such poor language": A chemist's perspective on writing in the discipline. *Across the Disciplines, 8*(1). Retrieved June 5, 2015, from http://wac.colostate.edu/atd/articles/stout2011/index.cfm

Sunderwirth, S. G. (1993). Required writing in freshman chemistry courses. *Journal of Chemical Education 70*, 474–475.

Van Bramer, S. E., & Bastin, L. D. (2013). Using a progressive paper to develop students' writing skills. *Journal of Chemical Education, 90*, 734–750.

Vázquez, A., McLoughlin, K., Sabbagh, M., Runkle, A. C., Simon, J., Coppola, B. P., Pazicni, S. (2012). Writing-to-teach: A new pedagogical approach to elicit explanative writing from undergraduate chemistry students. *Journal of Chemical Education, 89*, 1025–1031.

Walker, J. P., & Sampson, V. (2013). Argument-driven inquiry: Using the laboratory to improve undergraduates' science writing skills through meaningful science writing, peer-review, and revision. *Journal of Chemical Education, 90*, 1269–1274.

Yancey, K., Robertson, L., & Taczak, K. (2014). *Writing across Contexts: Transfer, composition and sites of writing*. Boulder, CO: University Press of Colorado.