The Language of Chemistry:
Maintaining Convention, Removing Ambiguity, and Educating Effectively

By Megan Roosen-Runge
Professor Bryan Smith
Spring 2009, Honors 213

Introduction

Communication, the process of transferring information, is an important topic to discuss and explore whether it involves the communication of ideas, emotions, opinions, or concepts. Much is taken for granted as far as the methodology of communication is concerned. The average person does not take the time to question the ways in which they take in and impart thoughts to others. As discussed in the curriculum of Honors 213, the field of mathematics uses a systematic and sophisticated approach to communicating theorems, propositions, and models. Using logic, axiomatic systems, and a commonly accepted set of symbols and language, mathematics is, at least at a fundamental level, interwoven into the vernacular of modern day communication. Other subjects, some less pervasive than mathematics, also adhere to a methodical approach to communicating the substance of their discipline – chemistry is such a subject.

Understanding the linguistic structure of mathematics enables one to engage with the material; just as understanding chemistry relies on a foundational knowledge of the chemical language. As Nobel Laureate Arthur Kornberg once stated, “much of life can be understood in rational terms if expressed in the language of chemistry.” During experimentation, chemists seek to solve a scientific problem. Given this, it is interesting to note that the way the solution is communicated is both the great challenge and the ultimate goal of the whole endeavor. There are varying perspectives on how one might look at chemistry as an 'international language,' one that explains "where we came from, where we are and where the world will allow us to go" (Bretz, 2001). Nevertheless, there exists a certain logic, knowledge, and language inherent in chemistry that is accessible to everyone. The language of chemistry is essential to people directly involved in science, but also critical in helping 'John Doe' understand the workings of the world he lives in. This paper seeks to better understand the language of chemistry via an examination of the development of chemical vocabulary and syntax, the logical structure characteristic of traditional chemistry education, and the pursuit of alternative educational curriculums

Creating Convention and Removing Ambiguity

Since 1919, the field of chemistry has had an organization, known as the International Union of Pure and Applied Chemistry (IUPAC), devoted to refining chemical language. They pride themselves on "uniting academic, industrial, and public sector chemistry in a common language." This is no easy feat, but IUPAC creates the foundation for all students of science, so that a person in Seattle is learning the same chemical language as someone in Munich, Germany. IUPAC's work has been to set conventions, particularly regarding chemical nomenclature, terminology, standardized methods for measurements, and atomic weights (IUPAC website, 2009). The establishment of standard values for all areas of chemistry, which requires thorough and accurate experimentation, is an ongoing venture of IUPAC. In doing so, IUPAC enables scientists both in chemistry and in chemistry-related fields to maintain a good level of consistency in their scientific pursuits.

Perhaps the most well-known contribution that IUPAC has made in establishing a chemical language is IUPAC nomenclature. This system of naming chemical compounds and describing the science of chemistry includes the rules for naming organic and inorganic compounds. Additionally, they prescribe the use of symbols for physical quantities and define technical terms used in all sub-areas of chemistry (IUPAC-Wikipedia, 2009).

The overarching goal of chemical nomenclature is to remove the ambiguity when identifying compounds. In other words, no single name should refer to more than one substance, although a single substance can have more than one name. There is a hierarchy to naming that allows the material to compliment the right audience; common names, familiar to a more general population, can be used to convey ideas in less complex or scientifically strict publications, while formal names are found in research journal articles. Fortunately, the standards IUPAC has established help to maintain consistency naming.

Scientists began to establish this system of nomenclature about the time of the alchemists. While Lavoisier was the first to make a distinction between elements and compounds, it was the French chemist Louis-Bernard Guyton de Morveau who published his recommendations in 1782, hoping that his "constant method of denomination" would "help the intelligence and relieve the memory." Yet, Guyton's proposals only concerned inorganic elements. Therefore, it was not until 1892, at a conference in Geneva, that chemists from around the world came together and proposed a more massive effort to standardize the language of chemistry.

IUPAC maintains and updates the standards that had eluded scientists for centuries. Now, modern scientists take IUPAC nomenclature for granted and most science students do not even realize the significance of IUPAC until they are introduced to it in more advanced college classes. Nevertheless, chemistry has a bona fide vocabulary and source of grammatical convention. The question as to the effectiveness of this language is then best seen via the classroom.

Setting the Groundwork

For some reason, chemistry is often given the stereotype of being 'hard,' 'frustrating,' or 'too complicated.' For example, a college science student might need to identify a substance, portray the molecule on an atomic level, and recognize how to write its formula using a preordained set of symbols. Because chemistry is difficult for many people, for many reasons, one of them being the necessity of analyzing and synthesizing concepts rather than relying on rote memorization. Because of this challenge to students, more and more universities are adding or exploring the development of courses that involve studying the "Language of Chemistry," in hopes of offering a new perspective on the subject.

Cara Hanes, a science teacher, chose to create a science experience for students that promotes student confidence and overall scientific literacy (Hanes, 2004). To do so, she took an approach that incorporated multiple intelligences and various learning styles. Knowing that the language of chemistry involves describing the arrangement of atoms in a reaction, writing chemical equations, and understanding the syntax of chemical words, Hanes hoped to hone these skills in her class. Important features of her methodology include linking new information to previous learning, utilizing visual aids, encouraging small group work, and linking chemical language to situations students experience in everyday life.

Breaking it down into steps, Hanes first focused on the chemical formula. First, one must recognize clues given in the chemical name that hint at the chemical equation. To tackle a chemical formula, one can approach it as a task of decoding or translating. Next, the chemical formula must be deciphered into chemical symbols and then into the corresponding elements, while also parsing out the number of atoms of each element needed for the desired chemical bond. There is a set of prefixes that students must become familiar with, such as *mono-, di-, tri-, tetra-, penta- and hexa-*. To help solidify these concepts in students' minds, it is often appropriate to use visual representations, either with 3-D models or on paper. If using paper, another subset of chemical language must be addressed – how can one represent atoms, bonds, charges, etc? These conventions have to be learned as a part of the chemical vocabulary.

Learning how to recognize elements of the periodic table is something that takes either pure memorization or consistent practice. Once a student can manipulate the chemical symbols effectively, they have to incorporate the mathematical balancing act involved in pairing charged species. Hanes uses exercises that continually build on one another, reinforcing key concepts and expanding on them gradually, to teach chemical language to her students. With the chemical formula as an accomplished learning objective, students move on to the chemical reaction. At this point, students have developed some of the vocabulary and a bit of the grammar necessary to form 'chemical sentences.' Mastering the formation of chemical reactions, therefore, is just learning about the syntax of chemical language.

Most science students, and certainly chemistry students, encounter the concept of the 'mole.' The mole is an extraordinarily large number, something that is used to quantify things at a molecular and atomic level. When we talk about atoms, we say there are $6.022x10^{23}$ atoms in one mole. Such an enormous number is hard to understand in concrete terms, so Hanes worked to incorporate the concept into the schemata of chemical reactions, and looking at the mole as central to the chemical reaction. Again, this is placing new information in the context of previous learning. There are many layers to chemical language and nuances that take serious effort to master, but if people are taught chemistry from various perspectives, then "all students can access the language of chemistry (Hanes, 2001).

Empowerment via the Language of Chemistry

Along the lines of alternative approaches to teaching chemistry, a college course was designed for nonscience majors "to introduce these students to how chemists study problems encountered in nature and to develop the necessary chemical concepts required to understand several particularly interesting biological phenomena" (Bretz, 2001). The creators of this class chose to overcome the obstacle of teaching 'about' science, rather than teaching science itself.

However, when gearing a class towards nonscience majors, many thought it appropriate to lecture on topics 'about' science, since this often includes the intersection of science with personal and social concerns.

Most frequently, educational institutions have utilized either the 'survey' or the 'foundation' method for teaching science courses (Bretz, 2001). The survey model, usually pointed at nonscience students, involves a barrage of facts at such a superficial level that students are incapable of gaining any real understanding from it. On the other hand, foundation classes concentrate on "a set of concepts, principles, laws, and theories regarded as required for more advanced study in that discipline" (Monaghan, 1998). The current line of thinking is that neither of these models is appropriate for introducing chemistry to 'the masses.'

A case study was done at Youngstown State University, exploring the effectiveness of a new course entitled "The Language of Chemistry" in meeting objectives related to "empowering students from any discipline with the knowledge, language, and logic necessary to understand [three to four case studies in organic and biological chemistry]" (Bretz, 2001). The case studies were designed such that the concepts students learn about are introduced on a 'need-to-know' basis, so that knowledge is not introduced just for knowledge's sake. Each topic presented is put within a historical and social context, so as to complement the scientific foundation the students are developing for themselves. This approach falls in line with the construct of meaningful learning, discouraging the formation of "non-arbitrary ideas in the learner's mind" (Ausubel, 1963). In other words, students were given the tools necessary to connect concepts just learned with ones learned previously. This puts chemistry in context, so that information is not learned in a disjointed and irrelevant manner.

As a part of this case study, the professors gave students the opportunity to give feedback on the course. There was no statistical analysis conducted, instead the success of the course was determined based on qualitative data. Ultimately, when surveyed, students said that they found the case study approach enjoyable, since they could see how science is done, how scientists talk about their work, and what causes them to be curious. Teaching science with effective communication as a primary goal seems to not only grant people the chemical foundation necessary to understand more processes in everyday life, but also engage with material in a manner not conducive when encountered in typical teaching methods. While having a separate course just on the "Language of Chemistry" may be impractical, adopting alternate teaching approaches and appealing to different learning styles, as Hanes did, is also greatly beneficial.

Conclusion

As has been shown, the language of chemistry requires not only the establishment of strict conventions, but also the flexibility needed to engage as many people as possible in the subject. IUPAC has served for almost a century as the organization of standardization in the field of chemistry, thereby removing inconsistencies in reference and experimentation and fostering fluidity in global scientific communication. This solves only part of the linguistic puzzle, however, since students of science and students outside the sciences benefit most from understanding the world around them in the context of an accessible language. Thus, the case studies mentioned and attention paid to empowering students to have a heightened awareness of their surroundings with the aid of chemical language, are perfect examples of how a change in perspective can both complement and enhance the standards set by IUPAC. Ultimately, the language of chemistry has a huge role to play in science and in the more mundane aspects of life. Just as we have to share a common mathematical language, we must embrace the language of chemistry, with all of its nuanced vocabulary and schematic grammar, to fully understand the significance of the chemistry itself.

References

Bretz, S.L.; Meinwald, J. "The Language of Chemistry." *Jour. College Teaching.* Dec 2001/Jan 2002; 31, 4.

Hanes, Cara. "Chemistry as a Second Language." *The Science Teacher*. Feb 2004 ; 71, 2.

"IUPAC" International Union of Pure and Applied Chemistry. 17 Apr 2009. http://www.iupac.org/

"IUPAC Nomenclature." Wikipedia: The Free Encyclopedia. 17 Apr 2009. http://en.wikipedia.org/wiki/International_Union_of_Pure_and_Applied_Chemistry_nomenclature

Reingold, D. "Chemistry as a Second Language." Bookend Seminar. 2005, 69.