# *Napoleon's Buttons:* Teaching the Role of Chemistry in History

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> The idea that momentous events may depend on something as small as a molecule—a group of two or more atoms held together in a definite arrangement—offers a novel approach to understanding the growth of human civilization. A change as small as the position of a bond—the link between atoms in a molecule—can lead to enormous differences in properties of a substance and in turn can influence the course of history.
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> *Napoleon's Buttons: How 17 Molecules Changed History (1)*

Many chemistry courses for nonscience majors either focus on the history of chemistry or employ a case study approach that connects chemistry to society, both of which are pedagogically sound and provide for excellent learning experiences for undergraduates. Very few of these courses, however, actually challenge students to think on a deep level about how an individual molecule can shape historical events and how these events can, in turn, have an impact on the field of chemistry. The unique focus of such a course is on the role of *chemistry in history* rather than on the *history of chemistry*. This article describes how such an approach was adopted at Dickinson College.

At Dickinson, all students must take two semesters of a laboratory science. These two courses can be taken in any department, and since this general education requirement was instated six years ago, none of our science departments offer the traditional two semester lab sequence that was previously offered here as well as at most liberal arts colleges. We are thus faced with the challenge of teaching students who will take only a single chemistry course during their college careers. As a result, there has been a shift in pedagogy among colleges and universities from the traditional survey courses of the past toward courses that are more relevant to the nonscience major. Many such courses are described in articles published in this *Journal (2–4),* including a recent one that discussed the goals and challenges of the introductory chemistry course for nonscience majors and in particular a unique chemical information assignment in which students researched urban legends, pollution in their hometowns, and the relationship between chemistry and their majors *(5)*.

Also recently appearing in this *Journal* was an article that presented the chemistry of MSG and described how it changed the food industry as well as our expectations for taste *(6)*. Such articles demonstrate that molecules indeed have a "story" that goes beyond the chemical facts and it is important to convey this if we are to produce scientifically literate students who understand the important role that science and technology have played and will continue to play in their lives.

In October 2003, I read a review of a new book titled *Napoleon's Buttons: How 17 Molecules Changed History* by Penny Le Couteur and Jay Burreson *(7)*. The book inspired me to modify my usual case study approach and try something new. I immediately knew that I wanted the class to write and title our own book, modeled after *Napoleon's Buttons*, with each student contributing a chapter on a specific molecule. This seemed to be a feasible goal with about 20 students expected to enroll in the course. Since this is also a laboratory course, my colleague who taught the laboratory component of the course also read the book and was equally excited about connecting laboratory work to such an approach. This article is our story of how one book shaped a course for us at Dickinson College.

## The Book

*Napoleon's Buttons* is an engaging account of 17 molecules (or in some cases groups of molecules) that have, like the tin buttons worn by Napoleon and his army, greatly influenced the course of history. Although the book only briefly recounts how the tin buttons crumbled in the bone-chilling cold, it becomes a metaphor for the way in which so many molecules have altered a particular course of events. Some of the molecules covered within the 17 chapters motivated voyages of exploration and discovery, some spurred advances in medicine, law, and public policy, while others were pivotal in determining what we eat, drink, and wear and how we take care of ourselves. Most important—and the underlying theme for each chapter in the book—is the notion that without these compounds the development of human civilization would have been very different.

*Napoleon's Buttons* is full of examples of the importance of the structure of each of the 17 molecules that affected history. The structural formula for each of these molecules is given and the important or "functional" aspect of each molecule is highlighted. Compounds composed of generally similar structure, but with some slight differences, are also presented. The authors frequently discuss how slight variations in the structure of a molecule can make a large impact on its properties.

For example, in Chapter 5 (Nitro Compounds), a simple comparison of the structures of *p*-nitrotoluene to *p*-aminobenzoic acid reveals that each compound has the same molecular formula ($C_7H_7NO_2$) and contains a benzene ring with two additional chemical groups located directly across from each other. However, the identity of the groups is different: a methyl and a nitro group are present in the nitrotoluene, while a carboxylic acid and an amine group are attached to the aminobenzoic acid. This difference in groups results in very different properties for each compound. *p*-Nitrotoluene can exhibit explosive properties while *p*-aminobenzoic acid (PABA) is nonexplosive. In addition, PABA can absorb UV radiation, which resulted in the widespread use of this compound in sunscreen products.

## The Course

### Classroom Component

The main goal for the classroom component of this course was to give students just enough background to enable them to delve into scholarly resources and master a molecule of their choice without overwhelming them with a blizzard of facts. The course was designed so that the material covered would reinforce the main theme of *Napoleon's Buttons*, which states that there is an intricate connection between the chemical structure of a compound and its properties, and it is in fact this connection that provides the key link between chemical structures and pivotal moments in history and the development of society. Whenever possible, students were referred to a particular chapter in the book that related to the material (Table 1). There was no conventional textbook for the course, but rather *Napoleon's Buttons* functioned as our main resource. Ample handouts were provided and students were encouraged to use textbooks in the library and the Internet to fill in the gaps and obtain diagrams and images of molecules.

The introductory chapter of *Napoleon's Buttons* covers the basics of chemical structures and bonding so that the average person can appreciate the 17 chapters that follow. Although the book is satisfying with the limited coverage of these topics, it is not sufficient for these students who need a bit more to be able to write stories about their own molecules. In addition, it sometimes leaves the students with additional questions. For example, the authors explain how carbon is always surrounded by four bonds, and sometimes there are double bonds, which count as two. They go on to say that "More than any element, carbon has tremendous variability in the way it forms bonds and also in the number of other elements to which it is able to bond. Thus, there are many, many more compounds of carbon, both naturally occurring and man-made, than there are compounds of all the other elements combined." Since this unusual versatility depends on carbon's ability to form hybrid orbitals, it is crucial for students to understand hybridization otherwise they do not understand how carbon can bond the way it does. Thus, understanding hybridization was one of the earliest goals of the course. It is very satisfying to see nonscience majors able to appreciate the fact that the electron configuration of carbon cannot possibly explain how it can form four bonds. Once students understand the basics of hybridization (we cover $sp^3$ and $sp^2$) they are in an excellent position to fully understand all of the molecules discussed in the book.

Sometimes while covering a topic, a specific molecule was discussed in some detail, and the class was told that this molecule was "fair game" for a student to use as a subject molecule. For example, after discussing $sp^3$ hybridization, chirality was discussed along with examples involving receptors and chiral recognition, and chiral drugs, specifically, Thalidomide. This gave the students a good example of a molecule that had an impact in many areas including the pharmaceuticals industry, the FDA, the history of England, Germany, and the United States, and the individual lives of so many people. As a result, they had a better feel for what a good choice of a molecule would be. Other molecules not covered in *Napoleon's Buttons* that were discussed during class included allotropes of carbon (diamond, graphite, buckyballs, and nanotubes), DNA, and cisplatin.

### Laboratory

The individual experiments chosen for the laboratory component of this course were not only designed to coincide with lecture topics, but also to reflect the same main theme: the influence of structure on the properties of various chemicals. Therefore, experiments chosen for the course corresponded to many of the chapters found in *Napoleon's Buttons.* Initial laboratory experiments (1–6) involved investigating substances ranging from simple to more complex structures (salts → basic organic molecules → complex polymers) and comparing properties of specific molecules within a general class of compounds (Table 2). In addition to the focus on comparative properties, basic underlying chemical concepts were also reviewed during prelaboratory lectures.

The next set of experiments (7–11) reiterated many of the previous chemical concepts, but with a focus on comparative properties of some important chemicals found in nature (Table 3). A good transition point between these two sets of experiments occurred at the polymeric level. Basic polymer structure and formation was introduced with synthetic polymers (experiment 6), before moving onto the isolation of the more complex natural polymers of DNA and proteins (experiments 7 and 8). Many students were fascinated with the ease at which one could isolate the natural polymers by simple manipulation of their inherent properties. The interest of the students increased even more with the subsequent experiments involving the analysis of caffeine and aspirin (two very necessary substances for survival among college students). Wrapping up the experimental sequence with acid rain investigations was of particular relevance since this environmental problem is prominent in Pennsylvania (average pH of

**Table 1. Lecture Topics Relevant to *Napoleon's Buttons***

| Lecture Topics | *Napoleon's Buttons* Reference |
|---|---|
| Atoms, periodic table, Lewis structures, and shape of molecules | Introduction |
| Intermolecular forces, chemistry of taste | Chapter 3 Glucose |
| Tetrahedral carbon, chiral structures | Chapter 16 Chlorocarbon Compounds |
| Isomers: cis and trans | Chapters 8 and 9 Isoprene; Dyes |
| Fatty acids | Chapter 14 Oleic Acid |
| Synthetic and natural polymers | Chapters 6 and 8 Silk and Nylon; Isoprene |
| DNA and proteins | Chapter 4 Cellulose |
| Hemoglobin and porphyrins | Chapter 17 Molecules versus Malaria |

precipitation: 4.2–4.3). Understanding the chemical processes leading to acid rain is a major step in developing methods to work towards the prevention of this problem. It is important to stress how an understanding of chemistry is beneficial to society as a whole, not only as seen in the examples contained in *Napoleon's Buttons*, but also for the future lifetime of the students.

An interesting and comprehensive laboratory component relevant to chapters in *Napoleon's Buttons* can easily be composed using experiments from widely available resources. For example, experiments complementary to the chapters referenced in Tables 2 and 3 are readily found in general or nonscience major chemistry laboratory manuals such as *Chemistry in Context (8)* and *Chemical Investigations for Changing Times (9)*. Similar experiments are also accessible online through custom laboratory manual sites provided by publishers of scientific textbooks and manuals: *Chemical Education Resources (10)* and *Catalyst (11)* allow choices from a large selection of experiments developed for various courses (general, health science, organic chemistry) and are focused on basic and applied chemical principles.

Therefore, a customized laboratory manual can be readily assembled to coincide with the chapters of *Napoleon's Buttons* presented in this article, or with additional chapters. For example, all of the common resources mentioned above include experiments involving the testing of foods or juices for ascorbic acid (Chapter 2 of *Napoleon's Buttons*) using a common titration technique as well as the analysis of various dyes (Chapter 9 of *Napoleon's Buttons*) using thin-layer chromatography.

**Table 2. Comparative Experiments Involving Increasing Levels of Structural Complexity**

| Experiment | *Napoleon's Buttons* Reference | Chemical Comparisons |
|---|---|---|
| *Salts (atomic level of structure)* | | |
| 1. Qualitative analysis: flame tests and anion identification | Introduction; Chapter 15 Salt | 1) Observe how metal ions exhibit a similar property (release light) but with variation (different colors) owing to specific arrangement of electrons. Observe how different anions affect the solubility of a ionic compound. |
| 2. Effects on melting ice (NaCl vs $CaCl_2$) | | 2) Observe how different amounts of NaCl and $CaCl_2$ affect the rate of melting ice to different degrees. |
| *Basic Organic Compounds (molecular level of structure)* | | |
| 3. Qualitative analysis: hydrocarbon and functional groups | Introduction; Chapter 14 Oleic Acid | 3) Observe how presence of multiple bonds and functional groups affect the solubility, combustion, pH, and reactivity of organic compounds. |
| 4. Synthesis of esters: combination of various carboxylic acids and alcohols | | 4) Observe how ester compounds exhibit a similar property (pleasant smell) but with variation (different scents) owing to the structure of the reactants that compose each ester. |
| 5. Decomposition of triesters (saponification of triglyceride) | | 5) Observe differences in solubility and micelle formation of free fatty acids, fatty acid salts, and triglycerides. |
| *Polymer Compounds (polymeric level of structure)* | | |
| 6. Synthetic polymers: nylon and Silly Putty | Chapter 6 Silk and Nylon | 6) Observe difference in properties of monomers versus polymeric form. Observe differences in polymer properties based on identity of the two monomers composing the polymer. |

**Table 3. Extended Experiments Involving Natural Chemicals and Processes**

| Experiment | *Napoleon's Buttons* Reference | Chemical Comparisons |
|---|---|---|
| *Natural Polymers* | | |
| 7. Isolation of onion DNA | Chapter 4 Cellulose | 7) Observe strength and flexibility of DNA strands owing to covalent and hydrogen bonding, respectively. |
| 8. Isolation of casein from milk | Chapter 6 Silk and Nylon | 8) Observe the disruption of multiple inter- and intramolecular bonds among 20 possible monomers composing various levels of complex protein structure. |
| *Nature's Drugs* | | |
| 9. Isolation of caffeine from tea | Chapter 13 Morphine, Nicotine, and Caffeine | 9) Observe how isolation of caffeine from cellulose, pigments, and tannins is possible based on differences in solubility, polarity, and boiling point. |
| 10. Synthesis of aspirin | Chapter 10 Wonder Drugs | 10) Observe differences in pH and reactivity of salicylic and acetylsalicylic acids. |
| *Pollution of Nature* | | |
| 11. Acid rain investigations | Chapter 16 Chlorocarbon Compounds | 11) Observe differences in strength of oxidizing agents necessary for conversion of $NO_x$ and $SO_x$ gases into acids responsible for acid rain. |

## The Assignment

The *Napoleon's Buttons* project, as we called it, consisted of two parts: an oral presentation and a final paper, both of which took the place of a written final examination. The project was worth 20% of the final course grade: 15% for the paper and 5% for the presentation. The oral presentation was approximately 10 minutes long followed by 5 minutes for questions and discussion, and the length of the paper was 10–15 pages. Since students were expected to use a wide variety of scholarly references, a college librarian met with the class early in the semester and also set up a Web page for the course. The Web page summarized all of the relevant databases and searching tools *(12)*.

The last three weeks of class were reserved for the project. Specifically, two 50-minute class periods were reserved for library work and instructor consultation on final drafts of the paper, including advice on the presentation. The remaining 7 classes were devoted to presentations and a contest to name the book. The culmination of the course was the compilation of our class book: *Monumental Micros: How 18 Molecules Changed History* (Table 4).

Student feedback on the project was overwhelmingly positive. Many students reported that they liked the way the course did not focus on facts and memorization but rather useful material that would relate to their majors, hobbies, and life in general. One student wrote: "I particularly liked the book choice. It was helpful in connecting science with everyday life. Because the focus was not on straight chemistry, but rather the intersection of chemistry, science, and the bigger world around us, it helped us to see the big picture." Another student commented: "I have always hated lab sciences, but this course actually got me more interested in chemistry. I am glad I had this experience, both in class and lab."

## Conclusions

The students in the class commented throughout the semester that they were very enthusiastic about the course and especially the project. Many said specifically that the goal of having a finished product—our own book—at the end of the semester was satisfying and gave the class a sense of camaraderie. Overall student feedback in the form of course evaluations was excellent (Table 5).

One result in particular that stood out in comparison to other years of teaching this nonscience majors course was the response to the statement "As a result of this course, I have become more interested in the subject matter." On a scale from 1 to 6 (1 being a strongly disagree and 6 being a strongly agree) the class mean was 4.83, compared to our chemistry department mean of 4.58 and an all college mean of 4.66. In past years, even when the course and instructor ratings were close to a perfect 6, this question has produced a mean of about 3 (mildly disagree). Perhaps the following student account speaks for the class as a whole: "This course made me realize that the major I have selected (English) is the right choice for me. But it surprised me that the impact of chemistry in history has been so significant. In general, chemistry alone does not spark my interest, but the impact that chemistry has on our lives certainly does."

Perhaps the most positive aspect of using *Napoleon's Buttons* as the focal point of a nonscience majors chemistry course is that the approach lends itself to a tremendous degree of variability and flexibility in choosing pedagogy and topics to cover. One can cover topics and background material that correspond closely to the book or cover totally different topics. Furthermore, the project can be changed, depending on class size and background. If the class is too large for each student to present a molecule or compose a book, the instructor can cover suitable molecules in class and treat each

**Table 4. Comparison of the Class Book to *Napoleon's Buttons***

| Chapter | *Napoleon's Buttons* | *Monumental Micros* |
|---|---|---|
| 1 | Peppers, Nutmeg, and Cloves | LSD: Lost in Science Deliberately |
| 2 | Ascorbic Acid | Nitric Oxide (NO): A Simple NO |
| 3 | Glucose | Steel: The Backbone of Modern Society |
| 4 | Cellulose | Olestra: Remedy or Obsession? |
| 5 | Nitro Compounds | Ephedrine: Heavy Chemistry |
| 6 | Silk and Nylon | Buckyball: The Monumental Micro |
| 7 | Phenol | Uranium: Heavy Metal |
| 8 | Isoprene | Gemstones: True Colors |
| 9 | Dyes | Silicone: It Can Shape History! |
| 10 | Wonder Drugs | Radon |
| 11 | The Pill | Effexor XR: When Prozac Just Isn't Enough |
| 12 | Molecules of Witchcraft | Prozac |
| 13 | Morphine, Nicotine, and Caffeine | Ethanol: A Friend Until the End |
| 14 | Oleic Acid | Ritalin: Miracle Drug or Cop-Out? |
| 15 | Salt | Sulfuric Acid |
| 16 | Chlorocarbon Compounds | Accutane: Medical Miracle or Disaster? |
| 17 | Molecules Versus Malaria | Petroleum |
| 18 | — | MSG |

**Table 5. Course Survey Results**

| Statement | Scale | | | | | | Mean (SD) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | CHEM 112 | All College | Chemistry Dept. |
| Materials used in this course were well chosen. | 0 | 0 | 0 | 3 | 11 | 4 | 5.06 (0.64) | 4.89 (0.94) | 5.07 (0.78) |
| Lectures were generally successful as learning experiences. | 0 | 0 | 0 | 4 | 8 | 6 | 5.11 (0.76) | 4.91 (1.12) | 5.06 (0.93) |
| Laboratory work was generally successful as a learning experience. | 0 | 1 | 0 | 1 | 8 | 8 | 5.22 (1.00) | 4.98 (1.02) | 4.98 (0.94) |
| Upon taking this course, I have a better understanding of the subject matter. | 0 | 0 | 0 | 4 | 7 | 7 | 5.17 (0.79) | 5.21 (0.89) | 5.25 (0.74) |
| As a result of this course, I have become more interested in the subject matter. | 0 | 0 | 2 | 5 | 5 | 6 | 4.83 (1.04) | 4.66 (1.29) | 4.58 (1.24) |
| I would recommend this course to other students looking for a worthwhile course. | 0 | 0 | 0 | 1 | 11 | 5 | 5.24 (0.56) | 4.80 (1.24) | 4.33 (1.43) |

NOTE: Eighteen students in the nonmajors chemistry course (CHEM 112) responded to each question using the following scale: 1 = strongly disagree, 2 = disagree, 3 = mildly disagree, 4 = mildly agree, 5 = agree, and 6 =strongly agree.

as a small unit. The project also lends itself to group work. In fact, two students in the class who were both psychology majors chose Ritalin as their topic. Neither wanted to abandon the topic, so they did the project as a pair and it worked very well. In short, the possibilities for classroom and laboratory topics and format are endless.

## [W]Supplemental Material

The student handout describing the project is available in this issue of *JCE Online*.

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