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BRIDGE Project Summary
2010/2011

Courses targeted

My two main teaching tasks are *Principles of Chemistry* in the Fall and *Biochemistry II* in the Spring. The course demographics and the course goals are quite different, but students have similar difficulties with learning, and my BRIDGE experience will inform both of these courses.

- *Principles of Chemistry (CHE120)*
    - Introductory course required for Behavioral Neuroscience, Biochemistry, Biology, Chemistry, and GEMS majors
    - Primarily Freshmen and Sophomores
    - Most are science majors
    - Two or three sections of ~40 students
    - Main ideas: energy (on a molecular scale), atomic and molecular structure, chemical reactivity, quantifying chemical reactions

- *Biochemistry II (BCH330)*
    - Advanced course required in the Biochemistry major and used as an elective in other majors
    - Juniors and Seniors
    - One section of ~12 students
    - Main ideas: Advanced topics in protein structure and folding, membrane structure and function, information flow from DNA to protein

Introduction

In "On the Persistence of Unicorns: The Tradeoff Between Content and Critical Thinking Revisited", Craig Nelson elaborates on William Perry's findings of the typical Freshman "simple view of knowledge that essentially precludes them from understanding complex issues" (169). Among several described aspects of this unsophisticated way of thinking, students with a "dualistic" view of knowledge see truth as "simple and eternal" (169). In the dualistic mode, knowledge is seen as a list of facts that are unambiguously true and simply require memorization. Another of Perry's aspects, as described by Nelson, is students' tendency to resolve any ambiguity through a mode of thinking called "multiplicity" (171). In this thought process, ambiguity is resolved essentially through guessing. As summarized by Nelson, such thinkers might base understanding of scientific concepts "on feelings or intuition, not on reasoned analysis" (171).

Sophisticated scientific thinkers, on the other hand, understand that humanity's grasp of nature is hardly the black-and-white understanding of dualistic thinkers; instead, our understanding is *evolving*, and our current ability to peer into the mysteries of nature is fraught with *ambiguity*. Even the giants of science have been unable to give "right" answers to questions of nature. Nelson asks, for example,

> What did physicists [in the late 19th century] "know" to be absolutely true beyond all possibility of doubt ever that we now know to be wrong? Important answers include the following: space was thought to be perfectly Euclidian (rather than bent hither and yon by matter), motion was thought to be Newtonian (rather than relativistic), and matter was thought to be indestructible (rather than interconvertible with energy). (171)

Of course physicists of the late 19th century, including such luminaries as Ludwig Boltzmann, James Maxwell, and Nikola Tesla, while unable to provide absolute truths, were still participating in the fruitful process of observation, hypothesis, experimentation, challenge, and rethinking that characterizes much of scientific inquiry since the Scientific Revolution. Rather than employing a thought process characterized by the "feelings or intuition" of multiplicity, most modern scientists make choices about explanations for natural phenomena by *controlled experimentation* and *objective analysis*. I hope, then, that my courses in the chemistry department will challenge students to mature from uncritical absorbers of facts into sophisticated scientific thinkers.

One (of several) suggestions offered by Nelson to combat dualism and multiplicity is the incorporation of the history of knowledge (including *recent* history, as will be discussed later in this essay) into courses about the knowledge itself (171). Rather than simply presenting a "fundamental concept," I have come to believe that discussing the real human struggles that led to the formation, refinement and acceptance of such a concept will help students (a) to learn the concept itself and (b) to internalize both the ambiguity of scientific exploits (are there observations that the current, "correct" model cannot explain adequately?) and the types of critical analyses required to determine which of several models is *most* correct.

Many introductory biology courses already incorporate a significant amount of historical subject matter into their curricula. In my experience as a student (Freshman biology at Denison University several years ago), the human struggles leading to current models of evolution and molecular genetics, for example, were made clear. It is difficult to present Charles Darwin's model of evolution without understanding alternative possible explanations. Accordingly, Lamarckian and Darwinian models for explaining the evolution of species were described, and the observations and thought processes and influences of Darwin (and others) were presented, allowing us students to make our own (guided) conclusions about which model was most appropriate. On a physically smaller scale, the possibilities that DNA replication occurs by "conservative" or "semiconservative" mechanisms were presented, and students analyzed the seminal data of James Watson and Francis Crick (the "double helix" model) and Matthew Meselson and Franklin Stahl (the use of heavy and light DNA strands). We then understood that the currently accepted semiconservative model did not simply arise from a textbook, and we were emboldened to delve into challenges and refinements to this model.

I contend, though, that traditional chemistry courses lag behind biology in the incorporation of history. Again in my own experience, this time from the stage, I have focused my teaching on the presentation of fundamental concepts (energy, atomic structure, the Periodic table, chemical reactivity) without overtly encouraging students to consider how these fundamental concepts were generated and tested. Such presentation dangerously reinforces Nelson and Perry's dualism and multiplicity.

Certainly, using history to teach chemistry is not a novel concept. A brief survey of the leading domestic journal in the field, *Journal of Chemical Education*, reveals a substantial conversation about the enhancing of chemistry courses through explicit reference to the process that led to current models. For example, in his article "Teaching Avogadro's hypothesis and helping the students to see the world differently," Brett Criswell advocates the explicit referring to the thought processes of Avogadro (19^{th} century) and others as a way for students to better understand the nature of gases and other forms of matter (1372-76). In another issue of the same journal, Ilya Leenson provides a detailed framework for the incorporation of seminal experiments of Rutherford, Avogadro, and others into the chemistry classroom (998-1003).

Summary of BRIDGE Project(s)

BRIDGE discussions and readings inspired me to begin a process of reimagining my courses to emphasize scientific thinking in addition to the learning of fundamental concepts. In both CHE120 and BCH330, I am focusing on placing a renewed emphasis on science as a discovery process by the explicit analysis of the struggles leading to development of knowledge.

History in CHE120. The structure of the atom could be presented simply by showing various pictures and discussing anatomical features. Simply put, the current view of the atom is that it holds a very tiny, very dense, positively-charged "nucleus" surrounded by a wispy "cloud" of negatively-charged electrons. Note that typically-encountered pictures of the atom reinforce common misconceptions of atomic structure and therefore preclude a sophisticated understanding of relationships between atoms. One example of many found during a quick Google image search is displayed in Figure 1A. A more 'accurate' picture of a Helium atom, with its cloud-like electrons and tiny (though incredibly dense) nucleus, is displayed alongside in Figure 1B. (Disclaimer: when one of the critical developers of our current picture, Nobel Laureate Werner Heisenberg, was asked how one should envision the atom, his famous response was "Don't try." The atom is just that weird. I believe, however, that understanding how atoms interact relies on a *relatively* sophisticated understanding of how electrons behave and a refutation of the simple 'planetary' picture shown in Figure 1A.) As an alternative to a presentation of atomic anatomy, I am developing modules to discuss (in an interactive manner) seminal experiments that led to models of the atom in the early 20^{th} century and, importantly, challenges and refinements to currently-accepted models in the 20^{th} and 21^{st} centuries. By leading students through (a simplified version of) this discovery process, I hope that they (1) will gain a more sophisticated understanding of atomic structure (and other concepts) and (2) will internalize the possibly cliché but important idea that science is a process, not a series of facts.

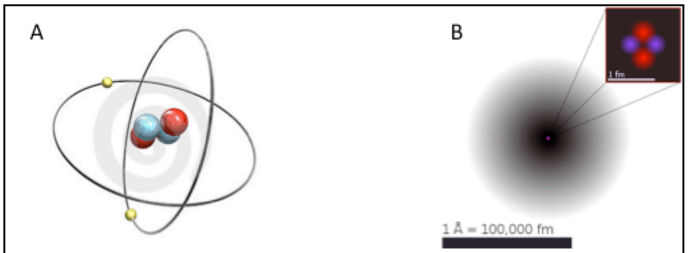


Figure 1. Models of a helium atom. (A) Students often conceive of the atom in a 'planetary model' (http://thumbs.dreamtime.com). Such a Newtonian conception prevents a sophisticated understanding of fundamental concepts such as the influence of the nucleus (blue and red balls) on the electrons (yellow balls), molecular structure, and chemical reactivity. (B) I would prefer students to picture a model that incorporates Rutherford's tiny, dense nucleus, which is surrounded by an electron 'cloud' (still only two electrons!) (image from Wikipedia). Particles on this scale (trillions of atoms exist in a space the size of a period) are exceedingly strange. The strangeness itself is for another class, but I hope that my students will at least begin to understand the problem

A brief version of the Powerpoint file accompanying the atomic structure 'module' is included in Appendix A. During the class period, I began by discussing the model of atomic structure that prevailed at the beginning of the 20th century (J.J. Thomson's "plum pudding" model). I presented a simplified version of New Zealand-born Physicist Ernest Rutherford's experimental strategy to test this model. The class then discussed (in a "think-pair-share" routine) their expectations for the outcome of Rutherford's experiment. Importantly, Rutherford's *actual* results deviate from typical student expectations (and from Rutherford's own expectations…). We then discussed, again using think-pair-share, what features would be required to generate such surprising results. The discussion wrapped up with a summary of Rutherford's words in which he came up with an early version of the current prevailing model of the atom ("Rutherford's nuclear atom"). Other similar historical classes in CHE120 focused on Coulomb's law describing electrostatic potential energy and the development of the Periodic table by Mendeleev and others. Importantly, throughout the semester we discussed observations that were inconsistent with a strict Rutherfordian model of the atom and how the model has undergone significant refinement over the past 100 years.

Specifically relating to atomic structure, I hope that covering the experiments that led to the model will help students develop a relatively sophisticated understanding of the content and, moreover, that they will internalize science as a process. Assessment of this hope will be a focus of future iterations of this class. Preliminary assessment, though, comes in three forms. First, based on initial impressions, I believe that students were more engaged in such a presentation of the material than they are with a typical textbook-style presentation of the concepts. Second, it is my impression that students performed well on simple exam questions designed to test their understanding of the scientific consequences of the experiments and processes covered and why initial expectations were not met. On the other hand, the third mode of assessment suggests that work needs to be done. On an exam, I asked students to draw a picture of what a "real molecule" looks like (for extra credit). While it's impossible to draw such an animal (see, for example, Heisenberg's quote about envisioning a much simpler atom), I was hoping that students would depict something Rutherford-like. The vast majority of students, however, reverted to classical (and incorrect) "solar system-like" pictures. A few, discouragingly, were not able to place the subatomic particles (protons, neutrons, and electrons) in appropriate places. Such disparate results support further work to refine the "historical" intervention and to directly study its impact on student learning. They also reinforce the idea that multiple types of intervention will be required to optimize the learning environment.

History in BCH330. I have a similar goal for my more advanced course: that students will learn fundamental contemporary concepts along with the ambiguities and objective mindset that accompanies all discovery. Toward this goal, I transitioned this year from a textbook-focused course to a course focused on reading "the literature" including both early historical papers and recent contributions to molecular biological studies. In our study of the process by which proteins gain their all-important three-dimensional shapes ("protein folding"), for example, we began by reading and discussing the 1959 paper that was a big part of biochemist Christian Anfinsen's 1972 Nobel Prize. Following an understanding of initial forays into understanding how proteins fold, we discussed two more secondary sources (review articles) from the biochemical literature outlining controversies in the field. Class discussions, then, focused on fleshing out the arguments and evaluating the relative merits.

As similar discussions of other biochemical concepts (such as membrane structure and function and transcription and translation) unfolded, we similarly started with reading and discussion of seminal papers in the field and followed up with more recent papers, usually primary literature papers. In addition to an explicit discussion of how fields of study unfold via refinement and correction of established models, student focus on reading the literature (rather than a textbook) helped to hone their analytical skills and ability to think critically about the work of "authorities."

A systematic study of the effectiveness of this strategy in an advanced biochemistry course will be forthcoming in future iterations. For now, referring to course evaluations (which for me are entirely qualitative: I included no "ranking" questions), eight of eleven respondents had "paper reading" (or the like) as all or part of their answers to the question "What did you like about the course?" (with zero respondents hinting that paper reading is an area in which the course might be improved.) These eight responses were (all verbatim):

- Paper reading
- The use of current reading materials, all the journal criticals
- It was not out of the textbook... learned how to read a paper
- Reading all the papers
- Awesome instructor picked interesting readings and really challenged students to understand the primary literature.
- The course was very active and hands on. Reading and redirecting experiments to show real life problems.
- How we had to analyze what data means and how we were guided along.
- I liked reading papers as opposed to text book stuff.

Minute papers in CHE120. As noted above, altering course content to address science as a process is not sufficient to optimize the learning environment. In addition to modifying the content of my courses, then, I am working on making my class environments increasingly active and student-centered. As part of this effort, and utilizing encouragement of BRIDGE resources and discussions, I began to implement modified "minute papers" (Angelo and Cross) in CHE120. As will be discussed below, this idea was more intensively pursued in the second semester of my BRIDGE involvement, with consideration of BCH330. I have several rationales for implementing these informal writing assignments. Most importantly, by forcing (or encouraging) all students to write down their thoughts in a directed but informal way, I am encouraging them to struggle with ideas that those who do not participate in discussions could simply ignore until test time. This formative assessment exercise also gives me additional information about how students are dealing with the information. As discussed below (Future work), the development of appropriate minute questions and processing (are the answers discussed or simply returned? do they count for a grade?) are underway.

Minute papers in BCH330. As part of my effort to implement informal writing assignments (loosely based on the "Minute paper" described by Angelo and Cross (148-153)), I began using this intervention in earnest in Biochemistry II, which has a much smaller and more manageable contingent of students (11 in BCH330 vs. 100+ in CHE120). Here, I implemented two or three types of informal assignments. For each, I gave the students 10 to 15 minutes to write their answers, typically at the beginning of class. I then asked for, or called on, volunteers to share their responses, which were then discussed by the class.

One type of question was an open ended discussion of a concept that we were in the midst of discussing. For example, one question was "how do proteins fold." This particular question, by the way, and others like it, could be interpreted in several ways (what is the *mechanism* of protein folding, what is the *driving force* behind protein folding, etc). Two randomly chosen responses are transcribed (to improve anonymity) in Appendix B. A second type of question used several times was to ask students to think of implications of their readings by proposing "the next experiment." Such an assignment forced students to think about the quality of the work described in the paper, to process experiments in a creative way, and to express their ideas on paper. Note that these informal assignments and their subsequent discussions were graded on a zero, check-minus, check, check-plus basis. Overall, they had little direct impact on letter grades, but I believe that giving scores put enough pressure on the students to encourage them to put serious thought into the assignments.

Based simply on my qualitative opinion (no student commented on these exercises on end-of-semester evaluations), I believe that these informal assignments worked very well in this course. While this course has been active, I believe that informal writing adds an additional layer to the student-centeredness. Students are forced to express their thoughts in a durable way and therefore, I believe, they are better able to solidify their understanding OR to face their misconceptions. Class discussions also contributed to this enhanced confrontation with the issues at hand by enhancing the ability of students to discover, and to critique, their peers' thought processes. Furthermore, these formative exercises allowed students and me yet another lightly-graded mechanism to discover where difficulties lie prior to summative assessments.

Future plans

My BRIDGE experience is not over. My initial priorities as the formal stage of BRIDGE comes to a close consist of three goals. First, in the next couple of years, I will institute additional assessments of my ideas to change my classes. I will institute pre- and post-tests designed to assess students' beliefs about how science works and their level of critical thinking. I will also ask directed questions to determine how students feel about a renewed focus on history and about the use of informal writing exercises. Second, significant work needs to be done on the historical modules used in CHE120. I also need to work on the informal writing assignments. I liked how they worked in BCH330 (though there is obviously room for improvement), but as implemented, they would not work as well in CHE120. Keeping in mind the experience level of the students as well as the more unwieldy class size, my first step will be to make the prompts more directed. I will also try several schemes for weaving student responses into class discussions. Third, BRIDGE has inspired me to continue to explore the scholarship of teaching and learning, and I plan to continue conversations with colleagues in a variety of venues.

Works cited

Angelo, TA and Cross, KP. *Classroom assessment techniques: A handbook for college teachers*. John Wiley & Sons, Inc., San Francisco. 1993.

Criswell B. Teaching Avogadro's hypothesis and helping students to see the world differently. *Journal of Chemical Education*. 85: 1372-76. 2008.

Leenson, IA. Ernest Rutherford, Avogadro's number, and chemical kinetics. *Journal of Chemical Education*. 75; 998-1003. 1998.

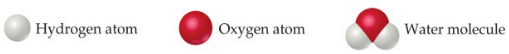
Nelson, CE. On the persistence of unicorns: The tradeoff between content and critical thinking revisited. *In* BA Pescosolido and R Aminzade, Eds., *The Social Worlds of Higher Education: Handbook for Teaching in a New Century*. Pine Forge Press. 1999.

Appendix

Appendix A: Powerpoint presentation used in support of a class (CHE120) discussion on atomic structure.

News flash: EVERYTHING is made up of atoms

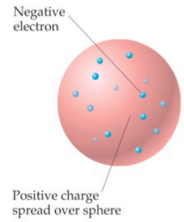
- That was not so obvious even through the mid 1800s!
- John Dalton, while studying the properties of gases, came up with "atomic theory"
  - Atoms of an element are *identical* and different from atoms of other elements
  - During chemical reactions, atoms combine to form compounds, but do not fundamentally change
  - A given compound always has the same *ratio* of elements



Dalton: atoms are little hard balls

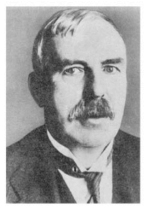
- HOW DO ATOMS REACT WITH EACH OTHER?
- 2nd half of the 19th century: scientists realize that the atom has *substructure*
  - *Positive* and *negative* parts
  - BUT WHAT DOES IT LOOK LIKE?

One guess: Thomson's "Plum pudding" model



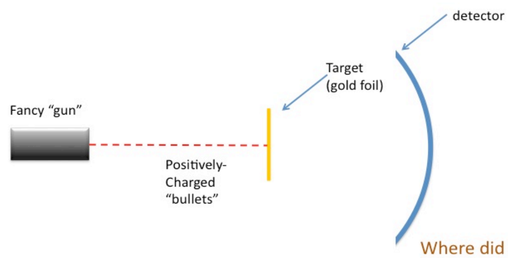
Ernest Rutherford

"The second Newton" -Einstein



- Set out to 'prove' the plum pudding model
- Designed a "gun" that shot little "bullets" of positive charge at a target
- Had a detector surrounding the target to see where the "bullets" ended up

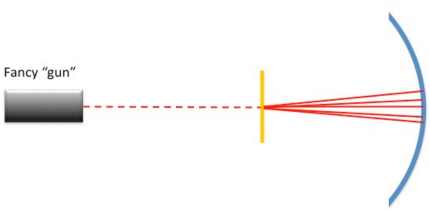
Rutherford's experiment



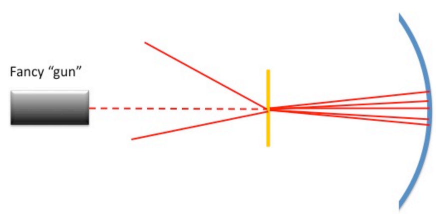
Where did the bullets go after hitting the target?

What he saw…

Confirmed the plum pudding model

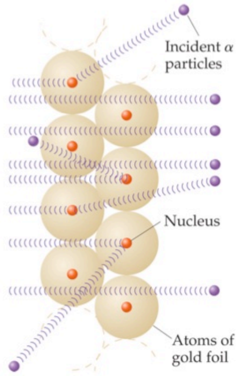


But wait…



Rutherford's Nuclear Atom

Since some particles were deflected at large angles, Thomson's model could not be correct.



The Nuclear Atom

- The atom is NOT A BALL with rigid edges
- Tiny, EXTREMELY DENSE nucleus
- The atom is mostly empty space

<u>Appendix B: Transcription of two in-class (BCH330) answers to the informal question "How do proteins fold?"</u>.

STUDENT 1: A protein folds based on backbone hydrogen bonding and assisted by side chain interactions. It folds in a model resembling a funnel, where the top is a featureless landscape of unfolded protein. As a protein begins to fold, it continues because it is energetically favorable. The protein will continue to fold until it reaches a native state. It can start from a multitude of possible denatured conformations, but in the end all make the same native state. Proteins do not generally get stuck in spots along the funnel due to evolution selecting for the lowest energy native state and smooth funnel walls. An organism with a poorly folded protein will be selected against evolutionarily. Proteins do not sample the infinitely possible conformations, and instead follow a direct path toward the native state.

STUDENT 2: Proteins start out in the unfolded state where they are in a form of a single stranded line. They fold up in to a globular state base on conformations that have the lowest energy, based on the funnel. Where proteins are forced down into lowering degrees of "needed" energy until they have reached the bottom at which point they are folded by h-bond and hydrophobic effects. Folding and energy is based off of the sidechain since the backbone is all the same.