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Beta-Testing New Approaches For First-Year Chemistry Instruction

By Dr. Donald J. Dahm (Rowan University), Dr. Mary Mumper (Frostburg State University), and Eric Nelson (ChemReview).

Abstract

In this article:

- Don Dahm describes his experiments in teaching well-prepared students two semesters of General Chemistry on the schedule of a one semester course. In 2008, Don's students averaged at the 63rd percentile (versus the 50th percentile ACS norm) on the *ACS General Chemistry Exam*.
- Mary Mumper describes her results with a new course in Preparation for General Chemistry. Of students who initially enrolled in the developmental course, 70% went on to General Chemistry. Of those, 75% passed first semester Gen Chem and 56% achieved grades of C or better.
- Eric Nelson discusses the *Calculations In Chemistry* tutorials that Don and Mary used as a course textbook and the possible implications of their results on efforts to increase STEM majors.

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New Options To Supplement Standard Texts

Under the federal Higher Education Act, beginning in July 2010, publishers will be required to offer to college bookstores prices for their textbooks that are both "bundled" with supplemental materials and "unbundled." The lower price for "unbundled" texts will allow instructors more leeway to experiment with a variety of supplements with minimal impact on the cost of textbooks for students.

Below, Don Dahm and Mary Mumper describe their recent experiments using the *Calculations In Chemistry* supplements, available online, as tutorials for calculations in first-year chemistry. Eric Nelson discusses the *Calculations* design.

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From Don Dahm

Rowan is a New Jersey state university with nearly 10,000 students. In chemistry, most first-year Rowan students enroll in the standard two semester General Chemistry, but most engineering majors (other than chemical) are scheduled for only one semester of chemistry. Consequently, about fifteen years ago, our department created for the first-year engineers and well-prepared physical science majors, an "Advanced Chemistry I, II" (AC I, ACII) course sequence. The course covered the topics in an order that was different than our regular series (and was somewhat more in depth), in an attempt to cover subjects most important to the engineers in the first semester.

AC I is offered each fall as two 75 minute lectures and a 2.5 hour lab block each week for 16 weeks, plus voluntary after-class problem-solving sessions once a week. I taught a portion of the AC I students in 2006, 2007, and 2008. My initial enrollments averaged about 70 students total in three sections. On average, about 75% were admitted engineers, 7% were physical sciences majors or pre-med, and 18% aspired to gain admission to the engineering college but had not yet been admitted.

In 2006, I taught AC I in the traditional style: I assigned reading in the text, lectured on everything I expected them to know, and worked some problems in class. In addition, it was necessary to use some of the lab time to cover all of the material.. Along the way, I became convinced that aspects of the course needed improvement.

1) We did not reach electrochemistry for the electrical engineers.

2) A large majority of the class was not able to do the harder problems from the test bank accompanying the text.

3) In the class after a well-crafted lecture explaining an important concept, many students would act as if they had never heard of the concept before.

With the permission and support of my department, I embarked upon experiments in course changes. ACI became an accelerated first course in college chemistry, intended to teach as much of the content of General Chemistry as possible in one semester. The second semester then became a truly “advanced” course.

In 2007, there was no attempt to change the structure of the course in sections other than mine. In 2008, I became the course coordinator, and the instructors of all sections were asked to use new structure.

Goals of the Experiment

While the primary goal was teach the AC I students all of the labs and content of standard General Chemistry in a single semester, I set for myself a second goal: To see if the material could be taught without using one of the conventional texts, due to my concerns over length, student comprehension, and expense. To evaluate the results, three standards were chosen:

1) scores on the *ACS Examination in General Chemistry* covering two semesters;

2) the number of labs completed during the semester; and

3) the student retention (and / or D-F-Withdrawal) rate.

Tools

A colleague supplied me with a website { www.ChemReview.net } that covered most (but not all) of the “calculation” subjects in general chemistry. The modules were also available as printed workbooks labeled *Calculations in Chemistry*.

The *ACS Official Guide to Examinations in General Chemistry* was also used for assignments, to expose the students to the content and style of the test on which their performance would be judged. In my sections, students were asked to purchase the printed versions of these two supplements as their primary "textbooks."

Procedure for Class

Each General Chemistry topic was covered as follows.

1) *Calculations* modules were assigned before lectures began for the unit.

2) Each week, there was a conceptual lecture and a lecture in preparation for the lab. Lab assignments included supplemental problems for which answers were not provided, and those problems were graded.

3) Supplemental reading was assigned by handout, by topic in a reference book, or on the web. The text *Chemistry: A project of the American Chemical Society* was made available to the students. It covered the material we wished to cover in eleven chapters, rather than the usual 20 plus. This allowed instructors to use a more conventional teaching scheme while still aspiring to the main goal of the experiment.

4) An assignment was made in the *ACS Guide*.

On a convenient class day, there would be a Test / Quiz on the previous week's material (from a textbook question bank) and on the current week's *Calculations* assignments (usually using quizzes provided by the *Calculations* author). Problems assigned with the labs were graded.

There were four major tests, one at the end of each course segment. In 2007 and 2008, the Final Exam was the *ACS Exam*.

Internet Use

All assignments were posted on the WebCT homepage, and homework assignments were often assigned from posting on the internet. In addition, in 2008, the *Calculations* modules in *Ksp*, thermodynamics and electrochemistry were published just before they were assigned to students and were distributed via posting on the *Calculations* website.

Results

- In 2007, on the *ACS Exam*, 52% of students scored above the ACS median percentile.
- In 2008, with additional topics covered in the *Calculations* modules, students averaged at the 63rd ACS percentile (versus the ACS norm 50th percentile), with 67% scoring above the ACS mean and median. Only 10% of students scored at the 25th ACS percentile or below. (In the AC I sections taught by other instructors in the more traditional manner, 2008 scores on the two semester *ACS Exam* after one AC I semester were somewhat lower, but encouraging enough to call the entire experiment a success.)
- The number of labs that my students completed increased from 10 in 2006 to 12 in 2007 to 15 in 2008.
- Both years, the overall DWF rate in my sections was approximately 25%, somewhat lower than seems to be the norm at the end of two semesters of General Chemistry. A disproportionate number of withdrawals came from students who had not yet been admitted to the College of Engineering.

- The amount of class time spent working problems was considerably reduced and time spent in "help sessions" was significantly increased.
- In 2008, students were asked to complete 200 or more problems in a problem notebook (about 14 problems per week) from among the recommended assignments. Of the 13 course A's, 10 students had completed 180+ problems by 11/30.

My conclusion was that the concept of covering a full year's course material in a single semester was shown to be feasible for this group of well-prepared students.

The bright spots were the *ACS Exam Guide* and the modules from *Calculations in Chemistry*. The *ACS Guide* does a better job of teaching the reasoning steps in the solving process, but the modules do a far better job of teaching the concepts. I found both to be a good source for homework problems, though an additional source for more difficult problems is needed. (One of our other instructors has developed such a supplemental problem set.)

Costs

In my current course design, we encourage the student to select a (used) textbook of their choosing as a reference, especially diagrams, difficult problems, and many "qualitative" topics not covered in enough detail in the *ACS Exam Guide* or *Calculations in Chemistry*. The students who plan to take ACII are asked to select the text for that course as their reference.

Under the new rules for pricing textbooks that apply next year, the mix of an unbundled standard text and the two supplements for should be possible with no significant change in the cost of textbooks.

[For additional detail, see www.*ChemReview*.net/ReptToRowanFaculty-AC1.PDF . While the department desired to have him to be active in teaching the new course again this year (2009), he is currently on a leave for one year. The "experiment" continues, although with some modification.]

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From Mary Mumper

In 2005, our department initiated a course in Preparatory Chemistry (Prep Chem) with the goal of improving the success rate of students in General Chemistry. During the planning for Prep Chem, I found the modules from *Calculations* via search on the internet. Students in Prep Chem were asked to purchase the printed *Calculations in Chemistry* Volume I (including stoichiometry, solution chem, and redox balancing) as textbooks.

Most often, Frostburg students express interest in General Chemistry to meet the requirements for majors in health and sciences. Based on a placement test, about half of the students who seek General Chemistry enrollment are scheduled into Prep Chem.

Of the approximately 130 students in the sections that most recently were enrolled in Prep Chem, 91 (70%) went on to our first semester General Chemistry for science majors. Of those, 68 (75% of those who continued) passed first semester Gen Chem,, 11 failed and 12 withdrew. Of the passing grades, 51 (56% of students who continued) were C or better, and 17 (19%) were B's and A's. The passing grades were majority C (34 students) with the remainder D (17), B (13) and A (4).

From another viewpoint: of the approximately 130 students who initially were enrolled in the developmental course, 52% both continued and passed first semester Gen Chem, 39% achieved grades of C or better, and 13% earned B's and A's.

My belief is that we rescued many of these students from failing General Chemistry. Two of the A students said they would not have survived without the prep course. In addition, after Preparatory Chemistry, about 40 students (~30%) of students decided that science was not the major for them. I count these as success stories also.

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From Eric Nelson:

I want to thank Mary and Don for their willingness to test new, and in places very different, methods to teach problem-solving.

Intent of the *Calculations* Lessons

Students are often assigned to "read the text and work the problems." How do assignments using *Calculations in Chemistry* differ?

Since 1994, extensive research, funded by the National Institutes of Health, has investigated problems encountered by students in comprehending what they read. The results of those studies offer guidance to authors on how to structure textbooks to help students extract meaning from text. The *Calculations* lessons are an attempt to apply the insights of this reading comprehension research to chemistry instruction.

If science-based science instruction can effectively move the review of math computation in time outside of lecture, more time will be available in lecture for demonstrations and higher level topics of the instructor's choosing. With this additional time for interesting science, it is hoped that more students will major in chemistry and other STEM fields.

Internet-Based Beta Testing

A second goal of the *Calculations* experiment is to test whether new approaches to teaching chemistry can be

- tested by potential users via the internet;
- improved via beta-test feedback from instructors, and
- instruct effectively in an "ebook" format.

Caveats

The *Calculations* tutorials are an attempted proof-of-concept, work-in-progress, beta version of one portion of a first-year curriculum. They are not intended as a complete course in chemistry. They continue to be modified based on user feedback and have not been edited for content or expression.

Content

The *Calculations* tutorials are designed to supplement standard textbooks. The focus is calculations: only one part of chemistry, but a stumbling block for many students.

The lessons are designed as homework: readings and problems with an emphasis on math and fundamentals. Some instructors have assigned the tutorials as a preparation for lecture and for more complex reading assignments. Others assign the lessons after a lecture on concepts as reinforcement with an emphasis on calculations.

Some differences between the *Calculations* lessons and traditional textbooks include:

1. Dimensional homogeneity, beyond dimensional analysis, is taught as a way to organize conversion calculations. As best I can tell, homogeneity is not employed or taught in other first-year science texts. Students report that this consistent, structured approach to problem-solving is effective and easy to use.

2. A mastery of fundamental vocabulary is encouraged before lecture. Research has found that if students have recently reviewed the meaning of the technical terms that they read in complex texts and hear during lecture, they better retain the meaning of what they read and hear.

3. Since 1990, computation has been de-emphasized in K-12 math curricula, and standardized test scores in math computation have declined precipitously across the nation. State standards in chemistry de-emphasize calculations in many states, and teachers must teach to those standards.

   Computation standards need to be restored in college preparatory programs, but until those changes are accomplished, many students will need additional instruction in computation if they are to succeed in STEM courses. *Calculations* teaches the computation topics needed for General Chemistry as homework, outside of lecture.

Format

The tutorials cover many (but not all) of the calculation topics in General Chemistry. They are available as PDF files for free downloading and printing at www.ChemReview.Net . The current lessons are copyrighted, but printing for class or student use is permitted.

The lessons are also available in paperback form as *Calculations in Chemistry*: 1,160 pages in three volumes at an inexpensive (black ink, non-profit) price.

Results

Because no two sections of students are the same, it is not possible to rigorously compare the results of one method of instruction with another. That said, experiments on significant-sized samples with significant effect-sizes should be replicable, and most instructors who implement class designs similar to Dr. Mumper's and Dr. Dahm's, with similar student populations, are likely to see similar results.

Beta-Testing

On the use of the internet to beta-test curriculum, so far, the results from the *Calculations* lessons indicate:

1. Many students are willing to use the internet to help in learning chemistry during study time. The *Calculations* website currently averages over 12,000 unique visits per month from students in a wide variety of settings.

The highest number of visits to the website (based on September 2009 data, in order of frequency) were from Harvard, Oklahoma State, Angelo State (TX), CUNY, Duke, CSU Northridge, Brown, Santa Fe Community College, Texas A&M, and Nevada – Reno.

2. Inviting instructors to beta-test the lessons has greatly improved their content. In addition to the testing and feedback provided by Drs. Mumper and Dahm, Dr. Richard Lavallee (Santa Monica College) and Dr. Aaron Fried (Glendale College) have been especially gracious in providing feedback on the lessons.

EBook versus Hard Copy

Is a PDF ebook as effective as a printed text at instruction? At this point in time, at least for the *Calculations* lessons, the answer seems to be: only for limited use.

In one experiment, Dr. Fried assigned the *Calculations* lessons in a first-semester section as ebook homework to be accessed on the web. In the next semester, first-semester students were asked to purchase the printed lessons as a supplemental text. His results indicate that occasional ebook assignments are completed by most students, but lessons in large numbers are completed more often from the printed text. Other instructors also suggest that students eventually tire of downloading and printing lessons from the web.

In 2009, concerns remain about assigning internet homework to lower income students who may have limited internet access. A few loaned printed copies from instructors or tutoring centers may address these needs.

Differences in the effectiveness of ebooks vs. printed books are likely to change with changes in technology and cost.

Interactivity

The *Calculations* lessons are designed to engage students, but the interactivity is "low-tech:" inviting students to fill in blanks, tables, and graphs. If students attempt to "work from the screen," for a significant number of the current exercises to be competed efficiently, the printing of selected pages is required. If the instructional methodology is found to be effective, "higher tech" interactivity could be added.

Increasing STEM Majors

How important is first-year chemistry?

1. Our nation's leaders support the proposition that the skills of our workforce in STEM fields determine our future prosperity. Federal grants to initiatives encouraging students to pursue STEM majors total $3 billion per year (*Education Week*, 9/17/08), with additional support from major philanthropies. If this substantial support for science education is to continue, it will be helpful to show progress toward meeting the nation's goals. First-year chemistry is a gateway (and bottleneck) to STEM careers.

2. Are concerns about a low number of American students in STEM majors justified?

   According to the National Science Foundation, between 2002 and 2006, the percentage of all doctorates awarded by U.S. universities to non-U.S. citizens was 44% in chemistry, 65% in computer sciences, 57% in mathematics, and 58% in physics. Of U.S. engineering doctorates awarded, only 33% went to U.S. citizens, while 37% were granted to citizens of China and India. In electrical engineering, only 23% of U.S. doctorates were awarded to U.S. citizens (*NSF InfoBrief* 08-301).

For a part of my career, I was a legislative representative for my faculty organization. I believe that most elected officials understand that substantial numbers of American-educated non-citizens remain in our nation and make enormous contributions to our economy. However, when economic times are tough, tax spending to educate non-citizens can become a political issue.

3. If we can help more children of our own citizens to be successful in STEM fields, it will strengthen public support for education and research, America's ability to compete economically, and the freedoms that our nation stands for.

If you may be interested in working with the team of instructors who are testing, reviewing, and upgrading the *Calculations* materials, please contact us at ChemReviewTeam@ChemReview.Net .

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