Active Learning in *Advanced Analytical Chemistry*, a Course for First Year Graduate Students

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Abstract

An active learning approach to the first-semester analytical course for entering graduate students is described. This involves teaching students to read and understand the literature by having them lecture on topics that they self-identify in review articles as beyond their initial ken. Passivity, on at least those topics where the students lecture, is avoided. Group camaraderie rather than competition is promoted, as is student/faculty collegiality. A term paper (graded in part by peer review) allows a student to master one area of the literature and identify the best way to solve some particular problem. Final exam performance is little different from ordinary, lecture-format courses. A weakness is that mathematics is avoided except where very explicit guidelines force quantitative considerations into the lectures.

Introduction and Motivation

The introductory course in analytical chemistry at the graduate level has commonly recognized goals:

1) to insure students have a general familiarity with analytical techniques
2) to fill in any gaps in their undergraduate training in chemical analysis
3) to promote use of the primary literature
4) to promote critical thinking about analytical problems
5) to promote a change in mindset from student-as-future-scientist to scientist-who-still-happens-to-be-a-student

For decades at the University of Illinois at Urbana-Champaign, these goals were fulfilled by having all entering students take Spectrochemical Analysis. This had a heavy laboratory component and, during its most successful years, was taught as much in research labs as in separate facilities. By the mid-1980's, changing times, changing equipment, and changing attitudes concerning the separation of teaching and research precipitated a shift in course timing and content. Spectrochemical analysis, stripped of its laboratory, was deferred to the second semester. In its place in the first semester, the late Prof. Timothy A. Nieman initiated a course covering all the topics normally covered in undergraduate quantitative analysis, instrumental analysis, and some of the material in Laitinen's *Chemical Analysis* (or, in second edition, Laitinen and Harris).[1,2] A lecture on use of the library was included. A laboratory component included experiments in optical spectroscopy, separations, and electrochemistry. While this laboratory, significantly evolved, continues to be an important component of instruction, it will not be of further concern in this paper.

After many years of teaching in this fashion, a pattern became evident. So much material was being covered so rapidly that sub-optimal amounts of learning were occurring. Those who had background in a given area learned more, while those with weak backgrounds floundered. Some topics seemed out-dated, yet were felt necessary as part of a solid technique-focused background. One year, Prof. Ralph Nuzzo[3] tried teaching the course straight from the current literature. He was frustrated at the holes in student backgrounds; simply finding hot literature topics evidently was not the answer to updating the course.

In 2003, the author's turn to rotate through Advanced Analytical Chemistry arrived. The thought of once again stampeding through all the same material, anticipating a mixture of blank stares (from those lacking background) and boredom (from those having it) was more than he could stomach. Having been told for decades by his mentor, Prof. John Walters,[4] "you learn what you teach, and little more," an experiment in active learning was tried, as reported herein. The approach is informed by the increasingly popular approach of Active Learning[5,6] (see for example http://www.pogil.org/).

Approach, Content, and Results

The restructured Advanced Analytical course had several means other than the traditional faculty-focused lecture/problem set "information push" format to attain the same ends as the course has always had:

1) Have students do the majority of the teaching.[7]
2) Have lectures focus on what students do not yet know, rather than on what they do know. The students participated in identifying what knowledge they lacked.
3) Develop a spirit of camaraderie through shared experience, collaborative learning,[8] and an atmosphere of open inquiry.

4) Require extensive use of the current literature, developing critical reading skills and a sense of when to seek out monographs, web material, and primary literature.
5) Test the acquired skills through authorship of a term paper[9] and through performance on a final exam.

The course has now been taught this way twice. A series of student questionnaires (see Appendices) helped tune the approach both during and between repetitions.

The opening exercise was to ask each student what his or her goals for the class were. They ranged from "learn something about Analytical Chemistry" to "get an A" to "learn to debug instruments." When it was my turn, I said my goal "was not to be the person who learned the most in the class." This precipitated a brief discussion of why lecturing is a poor way to learn, although it is a controlling way to teach[10] (that subset of the population that learns well from lectures[11] I suspect disproportionately become professors!).

The details of the syllabus were largely unknown at the beginning of the semester. The course was to be based on discussion of three (or, if time permitted, more) papers. The papers used during the two semesters are also given in Appendix I (note the different order of topics and different emphasis, to insure that student initiative was required during the second year). The students were told to read the first paper before the second class meeting, coming prepared either to critically discuss it or to earn a point apiece by identifying words, phrases, or concepts that they did not understand. In the first year, the paper was distributed in hard copy; in the second year, electronic distribution was used. The remainder of the first lecture included administration of the initial student survey (Appendix II) and a brief historical overview of chemical analysis.

As expected, the students were bashful about stating what they didn't know, so I started reading, telling the students to blurt out when there was something unclear. In the first year, it took four paragraphs before everyone had admitted the paper had them totally stumped. In the second year, it took only three paragraphs. This leveled the playing field – EVERY student had admitted in public that there was something they didn't know – and had seen that everyone else was equally clueless. Furthermore, each student had identified a word, phrase, or idea they didn't comprehend. That list was the set of topics for the first set of lectures! The topics were arranged in a logical order, then assigned to students in alphabetical order by last name. At this point, the use of the library was explained. A web connection was essential for teaching the class, as it allowed us to bring the library into the classroom. To my astonishment, students did not want to bring computers to class; they took notes by hand and did all their searching as homework. I predict that this will change in future years. Search tools such as *Current Contents*, *Web of Science*, and particularly *Scifinder* were emphasized, and the limitations of *Google* demonstrated (*Google Scholar* was announced near the end of the second rendition of the course and played no role in it).

Initially, students simply gave their lectures, after which I posted their supporting computer files (typically PowerPoint but sometimes PDF or Word documents) on the web. They suggested having lecture outlines in advance would be helpful, so starting in the middle of the first pass through the course advance posting was required. Note that what would have been viewed as an overbearing deadline if imposed by faculty was willingly, even eagerly, accepted when student initiated. Their first lecture was rigorously limited to five minutes; later lectures were targeted at 15-20 minutes, but were sufficiently concise that time limits were not stressed. The first lecture had made the point that careful planning allowed clear, but brief, presentation.

In addition to grading lectures for content, speaking style was critiqued. Informality, wording sloppiness, and the other typical pathologies of inexperienced public speaking resulted in reduced grades. Even tiny grading penalties were noticed; by the end of the course, lectures were meaty and to the point. The grading scale for each lecture was:

- Presenting anything: 2 points (just doing something got some reward. Of course, such an offset in a course graded on a non-absolute scale is meaningless, except that such points are important for student morale.)
- Reference selection: 2 points (graded on quality and reasonable quantity)
- Content of presentation: 2 points (typically, even before discussion with the instructor and revision, the content was meaty. It was, however, mostly qualitative.)
- Form of presentation (speaking style): 2 points
- Questions left over from or generated by presentation: 2 points (No lecture covers everything. These questions allow the students to note what they've chosen not to cover, and seeds the succeeding round of lectures.)

A hope was that the half-dozen lectures given during the course would improve the quality of literature seminars students would present in their second year. This goal was not achieved. While the stress level may have been slightly lowered (evidence weak, anecdotal, and inconsistent), many of the same organizational and presentation issues that previously dogged first-draft seminars were still in evidence. It is not obvious why the lessons of the introductory course did not carry forward.

How much faculty guidance in structuring the lectures is appropriate? Initially, I gave very little guidance. Student feedback in the intermediate course survey (Appendix III) indicated great disquiet at this excessive freedom. It was my impression that there was only weak correlation between the strength of a student's background and the amount of guidance they desired; self-confidence may have been a better predictor. During the second half of the first pass through the course, I let students self-select whether they discussed their lectures-in-preparation with me. In the second course, I insisted on at least a brief discussion of the direction the lectures would take prior to accepting a lecture outline file for posting. In each course rendition, there was only one instance apiece where lecture preparation was embarrassingly lacking. In both cases, this brought to light student problems that had little to do with the difficulty of the material.

The weakest part of the excessive freedom granted in the first course rendition was a nearly complete lack of mathematics in the lectures. I commented on this part-way through, but few picked up the hint. In the second rendition, I included the extent of mathematical description of the relevant topics in the grading scheme. This increased the amount of math in the lectures but not in student learning as revealed by exam performance. Students quoted, but did not internalize, the mathematical aspects of their subjects. The lack of problem sets may be to blame, but the weakest aspect of the current version of Advanced Analytical Chemistry is the abysmal lack of development of mathematical reasoning by the students. On the other hand, mathematics was hardly ever the strong suit of students in the faculty-lecture course format. While the author feels that much of analytical chemistry is "physical chemistry of systems complicated enough to matter," the students seem to think, as did one of the author's graduate school colleagues, that analytical is "p-chem without the equations!"[12] I have given some thought to having the introductory paper for Rendition 3 be a topic in which chemometrics is central.

A term paper further developed the students' critical thinking in several ways. First, they had to choose topics that were problem focused, then decide what techniques were optimal for solving the problem, and finally describe in detail how the characteristics of the technique could best be applied to the problem. Rough drafts of papers were due a month before the end of the course. I thoroughly critiqued the papers for content, style, and mechanics, but graded this draft leniently. The final draft was due on the last day of class. This draft was graded rigorously, but with little mark-up. In addition, groups of four students critiqued each others' papers, and part of the term paper grade depended on this peer review (in addition, I graded the reviews. Most showed some insight; a few were perfunctory). I provided reviewing guidelines (Appendix IV) and, at student insistence, examples (I critiqued two of my own review articles; if one is going to pan a paper, it might as well be one where the author won't be insulted!).

The final exam covered the science discussed over the course of the semester and included several new articles. The articles were announced in advance, and copies were attached to the final exam. If this sounds like the structure of some cumulative exams, this is not accidental. Illinois ceased giving "cumes" a few years before this Advanced Analytical experiment was tried. The skills formerly encouraged by "cumes" are now taught in this course.

In response to student complaints the first year that they didn't know what to expect on the final, an hour exam was added during the second course rendition. It had little effect on the final exam average (57.5 the first year vs. 50.5 the second, but weighted in the latter case by a student with significant language problems), but the students felt better about it.

Once the course was moving well, a fluid relationship developed between the students and me. "We have a lab report due next Tuesday; couldn't you lecture on something so we can start discussing the next paper on Thursday?" was one request to which I acceded. In the interstices between discussions of papers, I "enriched" the course by discussing topics that the papers missed that I thought were essential (activity per the treatment of Stokes and Robinson showed up both years, with addition of comments on ionic strength effects on kinetics in the second year, for example). The ample discussion, excellent rapport, and sense of ownership the students gained was, as expected, a strong point of this approach. Students really did begin to feel they were professional scientists who still happened to be students rather than the other way around.

Ancillary consequences of this approach are several. There are some cultures (for example, several in East Asia) where the definition of plagiarism is different than that in common use in North America and Western Europe. While all students receive ethics instruction upon arriving at graduate school, it is only when writing papers that the rules become meaningful. By having a term paper draft reviewed just by the instructor early on, students who need to learn U. S. practices are found quickly, and in a context where attitude adjustment can be both precipitous and humane. Most students when "caught" become apoplectic, fear that the zero on this one part of the paper assignment will lead to their professional ruin, and need to be calmed and reassured that adequate citation and recasting of ideas is all that is needed. Approximately 20% of the students needed to learn proper rewording and citation rules; only one student, thus far, didn't "get it" after one "reeducation session" on plagiarism. It is from these students that I have learned that my cultural perceptions are indeed accurate; they were taught to exactly reproduce, without citation, the words of an instructor, particularly in the introduction to a lab report or paper, as a sign of respect for that authority. Discussions on this point with Prof. Lisa Holland[13] and others suggest a general resource on plagiarism may be useful. A resource to this effect may be generated on ASDLib, at which point a hotlink to that resource will replace this sentence in a post-review update to this paper.

The upside of precipitating early student use of primary literature is readily appreciated. Many students dive into the literature far earlier and more aggressively than they used to. One student's discourse on time of flight mass spectrometry was so thorough, clear, and accurate, that when she later became a teaching assistant for a course in Instrumental Methods in Chemical Characterization and I needed to miss a class, I had her "pinch hit" in my absence by repeating her TOF-MS lecture. One can imagine the pride this engendered.

In summary, if the goal is to cover vast amounts of material, participatory lecturing is no less comprehensive than standard approaches. Depth is uneven, and mathematics gets short shrift. But professional development is stronger, material retention no worse, and the indirect consequences so useful that returning to regular lecturing in the "off" semesters is much less rewarding, at least to this author.

Appendices

I. Papers used to seed course. Note that it is not always obvious how these papers are "Analytical." That's part of what was taught: how to see the measurement issues in a novel problem.

Year I:

A. What substances are found in blood, how do they interact, and how do both the amounts and interactions of substances correlate with organism health? Root paper: S. Comazzi, S. Paltrinieri, V. Spagnolo, and P. Sartorelli, "Some Aspects of Erythrocyte Metabolism in Insulin-treated Diabetic Dogs," *Res. Vet. Sci.* **72**, 23-27 (2002).

B. How do we build a microprocessor, what materials issues are important, and what are the consequences of various material properties to the workings of the microprocessor? Root paper: B. Tracy, "Materials Analysis and Process Monitoring in Megafabs," *Proc. 28th Int. Symp. Testing Fail. Anal.* 69-75 (2002). (This paper was not available at Illinois, and so was only accessible through the Library's course reserves website.)

C. How does one make, characterize, maintain, replenish, and dispose of a hydrocarbon-reforming catalyst? Root paper: J. H. Sinfelt, "Role of Surface Science in Catalysis," *Surface Science*, **500** 923-946 (2002).

Year II:

A. Probing the nanoworld. G. Beaucage, H. K. Kammler, R. Mueller, R. Strobel, N. Agashe, S. E. Pratsinis, and T. Narayanan, "Probing the Dynamics of Nanoparticle Growth in a Flame Using Synchrotron Radiation," *Nature Materials*, **3**, 370-374 (2004).

B. Probing the biological world. M. A. Aller, J. L. Arias, M. P. Nava, and J. Arias, "Posttraumatic Inflammation Is a Complex Response Based on the Pathological Expression of the Nervous, Immune, and Endocrine Functional Systems," *Exp. Biol. Med.* **229**, 170-181 (2004).

C. Process analysis and the future of industrial chemistry. R. Vazquez-Duhalt, E. Torres, B. Valderrama, and S. Le Borgne, "Will Biochemical Catalysis Impact the Petroleum Refining Industry?" *Energy & Fuels* **16**, 1239-1250 (2002).

II. Initial Survey (Version from Year 2; Year 1 was nearly identical except it lacked the exercise in listing analytical techniques). Note that most questions both here and in the mid-course survey encourage students to ask related, but different questions, then answer them. Few availed themselves of this option except for the questions on course background, where some had unified "quant." and "instrumental" classes.

1. Current computer access
    a. Own laptop
    b. Own desktop
    c. Shared access to computer at SCS
    d. Must use a public site

2. Course background, reaction-based analytical chemistry
    a. Took course in quantitative analysis
    b. Took course that used wet-chemical methods for problem solving
    c. Never had a course that emphasized wet-chemical methods of analysis
    d. The course I had doesn't fit these categories. It's described in my writeup on the back of this sheet.

3. Course background, instrument-based analytical chemistry
    a. Took course in instrumental analysis
    b. Took course that used instrumental methods for problem solving
    c. Never had a course that emphasized instrumental methods of analysis
    d. The course I had doesn't fit these categories. It's described in my writeup on the back of this sheet.

4. Research experience
    a. I did research prior to coming to UIUC or I am currently in a research group
    b. I have not previously done research.

5. Presentation experience
    a. I am comfortable talking in front of 12 people interested in the same things I am.
    b. I am uncomfortable giving public presentations, but I've done it and survived.
    c. I have little experience talking in front of a group.
    d. I would be scared to death to talk in front of anyone about anything.
    e. None of these options fit. See the back for the answer to the question you should have asked.

6. Computer experience. For each possibility, rate from 1 (no experience) to 5 (expert), or supply commentary.
    ___ *Current Contents* or *Scifinder Scholar*
    ___ *Excel* or some other spreadsheet for computations and graphics
    ___ *Excel* macroprogramming or use of *Visual Basic* macros
    ___ Programming in at least one language (C, Pascal, Basic, Fortran, Perl, …)
    ___ *MathCAD*
    ___ *Mathematica* or *Matlab*
    ___ *LabView* or *LabWindows*
    ___ Other scientific or statistical software (please list)

(On reverse of the above) List every analytical technique you can think of.

Summary of Initial Survey Answers:

	Year 1 (2003)		Year 2 (2004)	
Question	Answer Distribution	Interpretation	Answer Distribution	Interpretation
1	11 8 3 2	Over half of students have laptops, but many still use desktops.	6 7 0 1	Half of students have laptops, which they use exclusively.
2	12 5 0 2	Equilibrium chemistry and quantitative analysis are nearly universal.	11 5 0 0	Same as prior year.
3	15 3 0 1	Instrumental analysis is even more universal.	9 6 0 0	Still universal, though not necessarily with the expected name.
4	15 yes, 1 no	Prior research experience convinces students to go to graduate school.	8 yes, 3 no	Or is it that prior experience biases the admissions process?
5	9 6 1 0	Public presentation worrisome to a significant fraction of students.	7 4 2 2	Same as prior year.
6	--		*Excel* the only "common denominator" (average 4.4)	Library searching and programming each came in at 2.4.

III. Mid-course Survey

As always, feel free to propose and answer the questions that should have been asked in addition to the questions that are here. Check all answers that apply.

1. The format of using primarily student lectures means:

___ The course is less work than regular lecture courses
___ The course is more work than regular lecture courses
___ I understand only my own material – everyone else's is opaque
___ I don't even understand my own lectures
___ I'm learning a lot
___ I like this format
___ Take or leave this format
___ Bad idea – have the instructor lecture
___ Good idea badly executed. Suggestions for improvements (see written comments)

2. Feedback on lectures has been:

___ Adequate
___ Inadequate
___ Timely
___ Too late to be useful

3. In-class discussion is:

___ Useful
___ Useless
___ Could be improved by (see written comments)

4. PowerPoint is a lot easier to read than some people's writing. It also takes longer to prepare than a spontaneous lecture.

___ It's worth the time to put together computer-centric presentations.
___ I'm spending too much time on presentation and not enough on content.
___ Chalk talks are more useful than computer presentations except for the pictures.
___ I read the other students' outlines before I come to class.
___ Netfiles is an inconvenient way to find other people's materials.
___ Netfiles is preferable to linking the files through WebCT
___ Please start copying the files to WebCT and organizing them there.

5. The lack of problem sets means

___ I learn on my own using the literature
___ I'm at loose ends to decide what's important
___ I learn "the math" on my own
___ I don't "learn the math"

6. With the current course structure

___ I read only the literature I need to give my lecture
___ I'm becoming more familiar with the literature and have learned to use primary sources
___ I read not only for my lectures but also to learn more about other people's topics
___ I read lots of the literature just to learn from it

___ As I go through the literature, I've learned a lot of chemistry that has nothing to do with the class in addition to what is required for the class

7. With 12 people in the class, each person lectures on average only every other week.
___ That's about right
___ Too many lectures to give
___ Too few lectures per person; with a class this big, regular lecturing would be preferable
___ Fewer, longer lectures are preferable (and would result in greater depth)
___ More, shorter lectures are preferable (and would result in greater breadth)

8. Lecture topics are more strongly directed by Prof. Scheeline this year than last year.
___ I wish things were as unstructured as they were last year.
___ I haven't talked to any second year students, so I don't know what this question is all about.
___ As long as we're learning, the amount of direction from above doesn't much matter.
___ More/less direction would make writing the lectures easier
___ More/less direction would make writing the lectures harder
___ More/less direction would make the course more rigorous
___ More/less direction would make the lectures more informative
___ Regardless of what other people think, I want more direction
___ Regardless of what other people think, I like the amount of direction we currently have
___ Regardless of what other people think, I want less direction

9. Having given two lectures
___ My presentation skills have improved
___ My presentation skills haven't changed
___ I'm less nervous than I was about getting in front of the group
___ Does Sigma need to add to their adrenaline inventory? They can have my excess supply the next time I have to lecture. The stress gets in the way of my learning.

10. Lectures could be videotaped.
___ That's the last thing I want to add to this class
___ What a great idea!
___ Don't care either way
___ It would help to be able to review all the lectures so I could pick up things I missed during class
___ It would help me improve my presentation skills
___ I'd buy the "collected lectures" DVD at the end of the semester
___ Taping just one lecture part-way through might be useful (early ones are obviously unpracticed, and later ones would provide sufficient time to make use of the feedback)
___ If I were taped, I wouldn't want anyone to see the tape but me
___ If the lectures were taped, I might sleep through a few classes and pick up the material off the web
___ If the lecture were taped, I'd take fewer notes

Summary of Mid-course Survey Answers:

1. Learning is greater when preparing lectures than when listening to other students lecture. All students thought they were learning something, but half thought they could be learning more with some alternate structure. The course is more work than normal courses.
2. Feedback (a brief email commentary and grade) were thought to be adequate.
3. Year 1: Classroom discussion was useful, but could be improved. Year 2: Discussion was useful. Likely reason for the change? Lecture notes were available in advance from the beginning in Year 2.
4. Year 1: Posting PowerPoint presentations is OK, but posting references is most important. Year 2: Computer presentations are so much easier to read than "chalk talks" that they should be required. Exchanging files in advance via Netfiles is easier than sending files to the instructor to post on WebCT.
5. Year 1, this is where it was revealed that too much freedom is a bad thing. Thereafter, students had to briefly describe their presentations to the instructor 2 days before their lectures and had to post their notes in advance. Frequently, they actually used (and then uploaded) revised versions of their slides, but lectures improved as did class participation. Mathematics was systematically avoided when not insisted on by the instructor.
6. Literature awareness beyond the narrow bounds of assignments was widespread.
7. Number of lectures (about one every 2 weeks) was OK, though more, shorter lectures would also be welcome. Editorial comment: many short lectures are significantly more work to manage.
8. Year 1, combined with Question 5, half the class wanted stronger direction while the other half liked the tremendous leeway. Year 2: half thought a reasonable balance had been found; half wanted more direction.
9. Most felt their presentation skills hadn't changed (while the instructor thought they were a lot better). Students were slightly more nervous about presentations than they had been at the beginning of the semester.
10. Videotaping so that only the speaker got a copy of the tape got nearly ½ the votes in Year 1. Taping so that lecture material could be reviewed got exactly ½ the votes in Year 2. Both years, at least half the class said DON'T tape.

IV. Guidelines for Evaluating Term Papers.

The students were instructed to read the term papers as if they were journal articles. Their reviews were guided by the following:

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- Is the problem significant? Is it timely? Can measurement science, broadly-defined, contribute to the solution of the problem?
- Is the scope of the problem appropriate for the length of discussion, so that depth and breadth are reasonably balanced?
- Is the choice of measurement approach appropriate, or was a "straw man," easy to critique but obviously sub-optimal, chosen? Alternatively, is the measurement approach over-kill, so that something cheaper, faster, but with poorer detection limits or less precise, would be preferable?
- Is the measurement approach adequately described, so that a typical first-year graduate student can understand what is happening?
- Is the method quantitatively critiqued? Is there sufficient quantitative argument that one can evaluate the methods and evaluate how they might work under altered circumstances?
- What is your overall rating? Various ways to look at this include: would YOU be willing to turn in a paper of this quality? If not, why not? Was the paper interesting to read? Did you learn something from reading it? Did it appear to be technically accurate? Did it adequately balance principle and specific detail? Did it critically look at the literature, spotting gaps, contradictions, opportunities for further work, or alternative approaches?
- Comment on grammar, spelling, or appearance if necessary. Always be on the lookout for plagiarism or infractions of academic integrity.

References Cited

1. Laitinen, H.A., *Chemical Analysis: An Advanced Text and Reference* (McGraw-Hill, New York, 1960).
2. Laitinen, H.A. and W.E. Harris, *Chemical Analysis: An Advanced Text and Reference* (McGraw Hill, New York, 1975).
3. Nuzzo, R., Urbana, IL (2001).
4. Walters, J.P., Role Playing Analytical Chemistry Laboratories Part 1: Structural and Pedagogical Ideas. *Anal. Chem.* **63**, 977A-985A (1991).
5. Ross, M.R. and R.B. Fulton, Active Learning Strategies in the Analytical Chemistry Classroom. *J. Chem. Ed.* **71**, 141-143 (1994).
6. Bransford, J.D., A.L. Brown and R.R. Cocking (eds.). *How People Learn: Brain, Mind, Experience, and School*, (National Academy Press, Washington, D. C., 2000).
7. Pinkava, A., The Feedback Lecture Method: Stimulating Active Learning. *Nursing Outlook* **33**, 257-258 (1985).
8. Williamson, V.M. and M.W. Rowe, Group Problem-Solving Versus Lecture in College-Level Quantitative Analysis: the Good, the Bad, and the Ugly. *J. Chem. Ed.* **79**, 1131-1134 (2002).
9. Whelan, R.J. and R.N. Zare, Teaching Effective Communication in a Writing-Intensive Analytical Chemistry Course. *J. Chem. Ed.* **80**, 904-906 (2003).
10. Wright, J.C., S.B. Millar and S.A. Kosciuk, A Novel Strategy for Assessing the Effects of Curriculum Reform on Student Competence. *J. Chem. Ed.* **75**, 986-992 (1998).
11. Stunkel, K.R., The Lecture: A Powerful Tool for Intellectual Liberation. *Chron. Higher Ed.* **44(420)**, A52 (1998).
12. Washburn, N., Madison, WI (1978).
13. Holland, L., Morgantown, WV (2005).