THE IMPACT OF A NATIONAL SCIENCE FOUNDATION COLLABORATIVE FOR EXCELLENCE IN TEACHER PREPARATION ON AN UNDERGRADUATE CHEMISTRY COURSE FOR NON-CHEMISTRY SCIENCE MAJORS

J. TYSON
Dept. of Chemistry, University of Massachusetts Amherst
Amherst, MA 01003-4510
tyson@chem.umass.edu

In 1999 and 2000 *Chemistry 312: Analytical Chemistry* for non-chemistry science majors (taken in the junior or senior year), was revised as a result of the instructor's involvements in the Center for Excellence in Teacher Preparation project and an NSF equipment grant. Changes included the introduction of a K-12 teaching requirement, more emphasis on co-operative learning and on inquiry-based exercises. These latter two pedagogical practices had more impact on the laboratory activities than on the classroom activities. Students in the laboratory were assigned defined roles in the groups and all groups undertook a three-week research project. Students' responses to the teaching requirement were (with a few exceptions in a class of over forty) positive, and several students identified themselves as future teachers. Responses to the group work associated with the laboratory and several homework exercises were less uniformly positive, with a significant number of students articulating a concern that their grades were compromised by the presence of weaker students in the groups. The grades awarded, the overall percentages and the exam scores of the students were compared for the years 1998, 1999, and 2000. There was a significant improvement in the overall percentages (and the exam scores) between 1998 and 1999, and between 1998 and 2000. Had the thresholds for the awarding of letter grades not been increased for 2000, there would have been 31 A's awarded to the 44 students who completed the course.

Introduction

Chemistry 312: Analytical Chemistry is a one-semester course for non-chemistry science majors. It is populated by a mix of seniors and juniors from several science disciplines, predominantly biochemistry. The detailed breakdown of the student years and majors is given in Table 1. The course is offered every spring, is worth four credits, and consists formally of three (50-minute) lectures and one (4-hour) lab per week. I have taught the course four times: 1992, 1998, 1999, and 2000. In Spring 1996, I taught the lecture section only. There are 35-45 students. I have three to four graduate student TA's to help with the lab sections.

The Journal of Mathematics and Science: Collaboration Explorations Volume 4 No 1 (2001) 71 - 83

The National Science Foundation (NSF) Collaborative for Excellence in Teacher Preparation (CETP) based at the University of Massachusetts Amherst is known locally by the acronym STEMTEC (Science, Technology, Engineering, and Mathematics Teacher Education Collaborative). In 1999 and 2000, *Chemistry 312* was revised as a result of (a) my involvement with STEMTEC as a summer (of 1998) cycle II participant, and (b) of the award of an NSF Instrumentation and Laboratory Improvement (ILI) grant for $60,000 (with an institutional match of $60,000). This ILI award provided funds to buy equipment as part of a program of revision of all of the undergraduate analytical chemistry laboratory courses (there are two other one-semester courses with labs: *Chem 315* and *Chem 513*). There is currently a nationwide discussion of the need to revise the undergraduate curriculum in analytical chemistry [1]. The Department of Chemistry at the University of Massachusetts Amherst has been actively involved in this debate [2, 3].

Table 1. Numbers of students taking *Chem 312* in Spring 1999 and 2000

	1999		2000	
Major	juniors	seniors	juniors	seniors
Biochemistry	12	8	22	11
Biology	3		1	2
Chemistry		1	1	1
Chemical Engineering		2		
Environmental Science	1	1	1	1
Food Science	1	2	2	5
Microbiology	1			
Natural Resources		1		
Totals	18	15	27	20

The students would be following the BA route rather than the more normal BS route.

Changes

I made several changes to the course as a result of STEMTEC and the ILI award. The most noticeable was to require a K-12 teaching experience. The most recent version of the course also featured research projects, in-class group work, a pyramid exam, more homework requiring the production of coherent prose, seven copies of the textbook [4] on short-term loan in the library, and the availability of some modern analytical chemistry equipment in the laboratory. The exact nature of these features were modified in 2000 in light of my experiences in 1999. Some of these changes had implications for the grading, details of which are discussed later.

The Teaching Requirement

The major impact of STEMTEC on the course, the inclusion of a K-12 teaching requirement, came initially as something of a surprise to the students. The students were given some leads—names, e-mail addresses, and phone numbers of teachers I had met through the STEMTEC workshops, and teachers who had participated in the previous year's activities, and details of the STEMTEC website—and told to make their own contacts. The task was not particularly onerous: students (in small groups) were required to participate in the teaching of a science topic to be decided in consultation with the teacher in question. After the initial contact was made, a total of two visits to the school was typically needed. The first was to meet the teacher and discuss the project in more detail, and the second was to deliver the lesson. To receive the credit for this part of the course, a 500-word report was required. To keep the students on task, regular progress questionnaires were handed out at approximately monthly intervals during the semester. This aspect of the course has been highly successful in getting students to consider (a) teaching as a career option, (b) the role of teaching as a strategy for learning, and (c) the responsibility of the professional scientist towards the next generation of scientists. All students were awarded the full 15% for this part of the course. In 2000, eighteen different classes were visited in twelve different schools. The classes were mostly elementary and high school classes with just one or two middle schools.

The following are extracts from the reports submitted by the students in the 2000 class. Almost all of these reports were positive in their attitude towards the experience.

> "This experience was definitely valuable to me as I am considering teaching biology or chemistry if I cannot get into graduate school for Forensic Science."

> "My experience of the STEMTEC program of this course allowed me to make choices and establish professional connections to last a lifetime. . . . I have recently been accepted into the STEP program."

> "I think I would be more inclined to teach after this experience."

> "I definitely need to consider teaching as a possible career."

> "As a result of this project, I have begun to look at teaching a little differently; I am now considering a career as a teacher, despite the relatively low salary."
>
> "I intend on becoming a science teacher and this experience helped to confirm my desire to teach."
>
> "I do not plan on becoming a teacher, but I think that professional scientists owe it to the community to occasionally go out into the K-12 sector and share their love for science."

Several students made comments along the following lines:

> "I am currently very seriously considering a career in teaching, although I would prefer to teach on the college level rather than the K-12 sector."

Several students reported that they were subjected to extensive questioning about "what it was like to be a college student."

As might be expected in a class of over forty students, there were some students who were not quite so enthusiastic:

> "This experience did not, however, open my eyes or encourage my interests in teaching. I have found that in the past, although I am smart enough to teach, I do not have enough patience to make a good teacher."
>
> "Now I know for sure that I do not want to teach for a living."
>
> "The value of the exercise for me was less than zero. . . I feel quite angry about being forced to complete such a thing as a requirement for a science course. . . I very much felt I was the victim of somebody's Ed.D. thesis. I think it would be much better for students to hear a thorough, well-informed lecture/presentation once a week, and perform homework, reading experimentation on their own in the meanwhile, than go to a weak chemistry class daily. Of course, my idea would be considered radical in an education system more concerned with controlling than educating students. This is unfortunate because high quality exposure to science in high school or even earlier is extremely important."
>
> "One suggestion that I have for the format of this component of the course is to do it earlier, say freshman or sophomore year. By the time people reach junior and senior year, I think they are pretty much set on what they want to become. Waiting until senior year is a little late to decide you want to become a teacher."

One or two students wanted the teaching to be optional (with extra credit available).

Of the 47 students who provided comments on the exercise, only two indicated that they considered the exercise to have little or no value. A further thirteen made comments to the effect that they would probably not have anything further to do with the K-12 sector. The remaining 32 students made comments to the effect that they would seriously consider some involvement in the K-12 sector, either as a teacher or as a professional scientist.

The Homework

There were twelve homework exercises: five of which required writing about chemistry topics mentioned in Zodiac (a novel by Neal Stevenson [5] and described by the publishers as an "eco-thriller"); five of which were solving numerical problems (one was exam number 2); one of which required providing one-word answers to questions relating directly to material in the textbook; and, one of which required writing suggestions for sample preparation and overall analytical methods. Efforts were made to get the students to work co-operatively on some of the exercises. Extracts from these different types of homework exercise are given below.

Type 1: Writing about chemistry

> On page 85 of *Zodiac*, readers are informed that "plastic is essentially frozen gasoline." Starting with the chemical composition of some typical "plastics" (in particular the sort from which a van-load of stuffed penguins might have been fabricated) and the chemical composition of gasoline, critically examine this statement. Include other relevant chemical and physical properties of the materials in question. What tests could be applied to a sample of plastic to identify it? How would you measure (a) the concentration of iso-octane and (b) the concentration of lead in gasoline?

Some of the writing exercises were accompanied by the following instructions:

> You are encouraged to work cooperatively on this exercise, and to share information about useful websites, textbooks, or other sources. This could reduce the amount of background research each of you has to do. Everyone must submit his or her own written piece, but you might consider implementing some peer review and editing.

Type 2: Solving numerical problems

> A thin film of sunscreen on a quartz plate is placed in an absorption spectrophotometer and the absorbance measured at 300 nm. What percentage of the ultraviolet radiation at 300 nm is transmitted if the absorbance measured is 0.35?

This type of homework was often accompanied by the following instructions:

> You may collaborate with other persons in the class and submit one set of solutions bearing more than one name. If you do participate in an exercise of this sort, then you need to prepare and sign a memo to me indicating that the submission represents a genuine collaborative effort involving each of the problems, and that you agree to accept a group grade for this homework. One memo with each of the group member's signatures will be sufficient.

Type 3: Providing one-word answers

The answers to the following questions can be found from reading Chapters 16, 17, and 18 in the course textbook.

Which of the following mixtures could not be separated by reverse phase HPLC?

(a) optical isomers of Naproxen
(b) the pesticides Carbaryl, and Methiocarb
(c) aflatoxins B_2 and G_2
(d) octanoic acid and 1-aminooctane
(e) fluoride, chloride, and bromide

Fill in the blanks with the most appropriate word (one word for each blank)

When trying to separate closely spaced bands, band _____ should be minimized. The rate of mass transfer between phases increases with temperature, thus increasing the column temperature might _____ the resolution. Octane, benzene and carbon tetrachloride are typical _____ compounds, whereas methanol, acetonitrile and ethanol are typical _____ compounds. Elution in HPLC with a single solvent composition is known as _____ elution. _____ elution in HPLC produces similar effects as _____ _____ in gas chromatography. The most common HPLC detector is the _____ detector, whereas for GC the detector which has almost universal response is the _____ _____ detector. Capillary electrophoresis can achieve plate numbers that are _____ times greater than those of chromatography. For the determination of chloride, the detection limit of _____ µg/L is best for _____ chromatography, but only _____ µg/L for an ion-selective electrode.

Type 4 Suggesting sample preparation and overall analytical methods

Many instrumental techniques require that the measurement be made on a solution Most samples for analysis are not solutions. Suggest procedures for preparing solutions of the analyte species for the following types of determination. (A) The determination of trace metals in a predominantly organic matrix (for example, the determination of cadmium, copper, and lead in cake mix); (B) the determination of a minor organic compound in a predominantly inorganic matrix (for example, the determination of PCBs in seagull eggshells); (C) the determination of inorganic components in an inorganic matrix (for example, the determination of iron, cobalt and nickel in dolomite); and, (D) the determination of organic compounds in a predominantly organic matrix (for example, the determination of amino acids in garlic).

Suggest overall analytical procedures (i.e., complete methods) for the following analyses. The determination of

(a) mercury in human hair
(b) sulfate, nitrate, chloride, phosphate in rain water
(c) caffeine in coffee beans
(d) dimethylarsinate in soil
(e) chromium in stainless steel.

STEMTEC Pedagogical Practices

With regard to the three pedagogical practices advocated by STEMTEC (students working in groups, inquiry, and alternative forms of assessment), there have been some changes. Students do work in groups in the laboratory class (for nine weeks out of the total of thirteen) and students were asked to work in groups on a number of in-class exercises. The laboratory group work has been a long-standing feature of this (and other analytical chemistry courses) where students perform experiments involving chemical instruments. With fifteen (or more) students in each lab section of *Chem 312*, there are not enough instruments to allow anything other than working in groups. For many years, the analytical chemistry faculty's approach has been along the lines of that pioneered by Walters [6,7,8] in which the students are assigned roles for the duration of the laboratory class. The most important of these is that of "group leader." The written instructions given to the students are reproduced below.

312 Laboratory Class: Group Experiments

The experiments to be done in weeks 5-9 and the project experiments (weeks 10-12) are to be performed in groups. Most of the groups will consist of three students, but there may be some groups of two and some of four. Groups will be assigned by the teaching staff. For each experiment, one of the group is assigned (by the instructor) to be the group leader. The other members of the group function as chemists working under the direction of the group leader. Each member of the group should have a different job (descriptions below) each week. For the experiments done in weeks 5-9, each group will produce only one report. It is the group leader's responsibility to co-ordinate the production and submission of the report. Each student in the group will get the same grade. The group task should be thought of as carrying out the requisite experimental work together with the production of a report. For the project experiments, each student will submit a separate report.

Each group member (including the leader) will write for each experiment a separate confidential report for the lab manager of not more than one page which will contain a description of what each person did in the lab, what each person did as a contribution to the report, how well the tasks were performed and how the group functioned (the good points as well as the bad). These reports should be handed directly to the laboratory manager and will be used as input in the award of points for "interpersonal skills." Each member of the group must read the information about the experiment before arriving at the laboratory and if there are any pre-laboratory exercises, these should be done individually. There will be a new group leader assigned for each experiment. Chemists should discuss their tasks with the group leader to ensure they cover all of the various tasks assigned to chemists during the five-week period.

The roles of the laboratory personnel are as follows:

Lab Manager (instructor)

Discusses experiment details with group leader initially, and later with other members of the group as necessary. Explains the operation of instruments and demonstrates their use. Functions as a consultant if problems arise that cannot be solved by the group.

Assistant Lab Manager (teaching assistant)

Discusses experimental work with group leader initially, and later with other members of the group as necessary. Explains the operation of instruments and demonstrates their use. Functions as a consultant if problems arise that cannot be solved by the group. Provides guidance in laboratory work. Ensures proper use of equipment and of laboratory techniques. Ensures adherence to safe working practices. Evaluates reports.

Group leader (student)

Researches the problem, discusses work plan with lab manager (or assistant lab manager) prior to start of experimental work. Discusses work plan with group members. Listens to comments, modifies plan. Co-ordinates work in lab, production of report and its submission.

Chemists (depending on group size there could be 1 - 3 chemists).

Chemists carry out tasks assigned by the group leader after discussion. These tasks could include:

Preparation of solutions for calibration of instrument
Preparation of samples for analysis
Measurements of all solutions (standards and samples)
Recording results in laboratory notebook
Sharing results with other group members
Copying results for other group members
Performing calculations (may include use of computer to plot calibration function)
Estimation of uncertainty in calculated values
Additional statistical evaluations or calculations
Writing parts of the report
Creating a visual record of the experiment

The structure for the laboratory group work was not significantly different as a result of my STEMTEC involvement, though the use of written individual reports was an innovation aimed at dealing with the problem of students who did not contribute fully to the group activity. A full 5% of the overall grade was awarded for interpersonal skills (see later); a low score in this category could easily affect the final letter awarded.

I reduced the number of in-class group activities in 2000 compared with the number in 1999, without any apparent ill effects. A poll of the students (written responses at the end of a class period) showed that about one-third of the class preferred lectures over in-class group work, one-third preferred in-class group work over lectures, and about one-third had no strong preference. Students were encouraged to work in groups for the homework exercises, and while they undoubtedly did this, they were reluctant to submit group solutions.

In addition to this resistance to the concept of homework groups, there was a certain amount of hostility towards the laboratory groups as well. Discussion with individuals revealed that the concern was mainly the feeling that there is a danger that their grade is compromised by the presence of weaker students. This probably arises from little or no exposure in previous classes to any kind of co-operative learning situation. In order to get students to work in groups, it is necessary to give credit for group work; however because credit is given, students are dissatisfied because of the perception of the influence of the weaker student(s) in the group. This situation is unlikely to change until students are introduced to co-operative learning early and often in their undergraduate careers.

The research project (worth 6% of the overall grade) was a genuine inquiry-based exercise. Several of the homework exercises required research prior to construction of the response. Almost all of the students regarded the World Wide Web as the first place to look for information. Very few students looked in the library.

None of the exams was multiple choice, so in that sense they were "alternative forms of assessment." Only about 40% of the overall score was awarded for the students' knowledge of analytical chemistry; the remaining 60% was awarded essentially for their abilities as students. Thus, compared to courses in which a higher percentage of the grade is awarded for knowledge of the content, it might be argued that this course represents the use of alternative methods of assessment. The pyramid exam was based on the concept of allowing students two attempts at an examination with a period in between, in which they could consult with each other. The two attempts were given relative weightings of 70:30. The exam selected for this mode was the third in a series of in-class exams and was given on two consecutive days (the UMass timetable occasionally produces a Monday schedule on a Thursday, thereby producing meetings on two consecutive days of a class which if offered on Mondays, Wednesdays, and Fridays). The exam contained numerical problems, true or false choices, fill-in-the-blanks, and essay responses. The second day's exam contained the following instructions:

> Read everything before doing anything and follow the instructions given at the end. The answers you hand in today will be worth 30% of the overall grade for this exercise. You do not have to rewrite solutions for which you wish the answer provided yesterday to be included. Indicate clearly which answers are being carried over (if any).

The "instructions given at the end", informed the students that they didn't have to answer all the questions ("Answer question 5, either question 1 or 3, and any other two questions").

Assessment of the Effectiveness of the Course

The overall grade (in 2000) was made up as follows, exams 35%, lab exercises 20%, homework 20%, teaching activity 15%, attendance 5%, and interpersonal skills 5%. There were four exams: three in-class "hour exams" and a final exam. One of the in-class exams was a pyramid of the form that the students took the exam twice (on consecutive days) with the points split 70:30 between the two exams. The exams were worth 5, 5, 10 (pyramid) and 15% (final) percent, respectively. The laboratory class consisted of experiments for which full instructions were provided and whose reports were awarded a total of 180 points, the laboratory notebook was assigned sixty points and the project 100 points. In 1999, the breakdown was a little different in that only 30% was awarded for the exams and the lab was worth 24%.

The percentage of the various grades awarded are given in Table 2.

Table 2 Percentages of grades

Year	A	AB	B	BC	C	CD	D	Totals
1998	39 (14)	28 (10)	17 (6)	11 (4)	0 (0)	3 (1)	3 (1)	100 (36)
1999	48 (16)	33 (11)	9 (3)	3 (1)	6 (2)	0 (0)	0 (0)	100 (33)
2000	39 (17)	32 (14)	23 (10)	0 (0)	2 (1)	4 (2)	0 (0)	100 (44)

Note: Numbers in parentheses are numbers of each grade awarded. For 1998 and 1999, an A meant 80+, in 2000 an A meant 85+. Each half letter grade corresponds to a 5 point band.

The mean overall percentages and standard deviations are given in Table 3 for the years 1998, 1999, and 2000, together with same information for the percentages on just the exams.

Table 3 Overall scores and exam scores

	Overall			Exams		
	1998	1999	2000	1998	1999	2000
mean	74.7	80.0	81.7	59.1	66.6	69.6
std dev	7.8	7.3	6.7	12.6	8.8	10.4
95% CI	2.6	2.6	2.0	4.3	3.1	3.2

Note: In 1998 and 2000 exams were worth 35% of total, in 1999 exams were worth 30% of total. Total numbers are given in the last column of Table 2.

These data may have some interesting properties. Assuming that there is no difference in the students' abilities over the three years and that the data are normally distributed, it may be deduced that the performance of the students has improved over the three years. There is a significant difference (at the 95% confidence level) between the overall percentages (and the exam percentages) for 1998 and 1999, and for 1998 and 2000. Had I not increased the threshold for the awarding of letter grades by 5% for 2000, there would have been 31 A's awarded.

It is always difficult to assign causes to effects that are observed in the teaching of classes of relatively small numbers of students over relatively short periods with what might be considered relatively minor changes in the pedagogy adopted. In comparison with the methods used in 1988, there has probably not been a significant change in the relative weighting given to the students' abilities as analytical chemists and the students' abilities as students, although the activities involved in the computation of the overall grade were considerably different. Thus, the improvement in overall performance in the course, as evidenced by the improved overall scores, is interpreted as due to the changes implemented. This improvement was evident for the two years following the changes made as the result of STEMTEC. One possible factor accounting for the improvements seen in 1999 and 2000 over the 1998 performances is the award of 15% of the grade for participation in the K-12 teaching exercise. However, the structure of the grading was such that this 15% for participation in the class replaced a similar percentage for similar activities in the 1998 grading scheme, and thus the real improvement observed may be attributed largely to the improved performance in the various examinations i.e., in the students' abilities as analytical chemists. ■

Acknowledgments

Financial support from NSF, though grants DUE-9653966 (STEMTEC) and DUE-9850636 (Valid Analytical Measurements in Undergraduate Analytical Laboratories) is gratefully acknowledged.

Bio

Julian Tyson has been a chemistry professor at the University of Massachusetts Amherst since 1989. He has a Ph.D. in analytical chemistry from Imperial College (London University) and thirteen years' experience of teaching at a university in the UK. His research is concerned with the characterization of the trace metal and organometallic components of materials.

References

[1] *Curricular Developments in the Analytical Sciences*, National Science Foundation, Washington DC, 1997.

[2] J.F. Tyson, "Education and training of analytical chemists: what is industry looking for in a B.S. chemist?" *Managing the Modern Laboratory* 2 (1996) 55-63.

[3] J.F. Tyson, *Analytical science for the next generation of scientists: the impact of two NSF-funded programs at the University of Massachusetts Amherst*, Paper presented at the annual conference of the Federation of Analytical Chemistry and Spectroscopy Societies, Vancouver, BC, 1999.

[4] D. C. Harris, *Exploring Chemical Analysis*, W. H. Freeman, New York, 1997.

[5] N. Stevenson, *Zodiac*, Bantam Books, New York, 1995.

[6] J.P. Walters, "Role-playing analytical chemistry laboratories, Part I: structural and pedagogical ideas," *Analytical Chemistry* **63** (1991) 977A.

[7] J.P. Walters, "Role-playing analytical chemistry laboratories, Part II: physical resources," *Analytical Chemistry* **63** (1991) 1077A.

[8] J.P. Walters, "Role-playing analytical chemistry laboratories, Part III: experimental objectives and design," *Analytical Chemistry* **63** (1991) 1179A.