1996

Education and Training of Analytical Chemists: What is Industry Looking for in a B.S. Chemist?

Julian Tyson
University of Massachusetts Amherst

Education and Training of Analytical Chemists: What is Industry Looking for in a B.S. Chemist?

by Julian F. Tyson

For the conscientious teacher, curriculum revision is an ever-present issue.

Abstract

The results of a survey of employers of B.S. chemists in the U.S. are presented. The 74 responses were analyzed to determine 1) what skills were important to industrial employers of B.S. analytical chemists, 2) how well prepared recent B.S. hires were in regard to these skills, and 3) what chemical instruments students should be familiar with. The results were validated by comparison with studies already published concerning the situation in both the U.S. and the U.K. Serious deficiencies were identified in the preparation of students in terms of their problem-solving abilities, knowledge of safe working practices, and communications skills. Students were considered well prepared in terms of quantitative laboratory skills, ability to work as team members, and knowledge of software capabilities. A mismatch between the contents of the instrumental analysis laboratory and what industry would like is apparent: Too much electrochemistry and not enough spectrometry and chromatography are being taught. The slow response of academia to expressions of concern by industry is attributed to constraints imposed by the U.S. standard pedagogical approach and to the problems faced by the conscientious faculty member in terms of allocation of time. Some suggestions are made for the basis of academia–industry dialogue and collaboration that would accelerate the processes of curriculum change that industry would like to see.

Dr. Julian F. Tyson
Department of Chemistry
Box 34510
University of Massachusetts
Amherst, MA 01003-4510, U.S.A.
Tel.: 413-545-0195
Fax: 413-545-4846
e-mail: tyson@chem.umass.edu

For the conscientious teacher, curriculum revision is an ever-present issue. For many teachers in post-secondary institutions, one of the relevant factors to be considered is the employment destination of the students. Whether such factors have any impact on what is taught to students is by no means certain, as it is by no means certain what the mechanisms and driving forces are for curricular revision in the U.S. Most university and college teachers of B.S. chemists will recognize that there are two distinct destinations for their graduates: further education (an M.S. or Ph.D. program) or employment in the chemical industry. There are, of course, many other destinations for B.S. chemists,[1] but the majority are likely to opt, initially at least, for further study or an industrial position. Most teachers recognize that there are differences in the curriculum content that might be considered the ideal for each of these tracks. Whereas teachers are well aware of what the graduate school route requires, they are less aware of what industrial employers of B.S. chemists might be looking for, and thus the needs of industry may not be in clear focus when curriculum revision is dis-

Key Words: *undergraduate curriculum, analytical chemistry, instrumental analysis, industry survey, employers' views*

cussed within the academy.

While there have been some recent statements concerning the education and training of students for subsequent employment in industry (see, for example, Ref. 2 and references therein), it is difficult to know 1) to what extent the views of the authors of one article are representative of industry as a whole and 2) to what extent the criticisms are leveled at Ph.D. graduates as opposed to B.S. graduates. There does not appear to be effective communication between universities and colleges, and industry, at the level needed to make individual faculty members aware of the needs of industrial employers. Such contacts as there are between the two cultures may well be confined to research collaborations, or the more rarefied atmospheres of Dean's or Provost's Advisory Boards. Contacts may be limited to relatively short visits by industrial personnel, during which there is limited time for general discussions regarding curriculum content when the main agenda item may be a seminar presentation or the discussion of research progress.

This paper presents and discusses the results of attempts by the author to clarify how U.S. industry views the preparation of B.S. chemistry graduates for employment as analytical chemists.

Experimental

The views of employers of B.S. analytical chemists were sought by means of a questionnaire survey. This was performed in two stages. In stage one, carried out in July 1993, 130 questionnaires were sent to analytical chemistry Ph.D. alumni of the University of Massachusetts, Amherst, currently working in industrial positions. In stage two, the questionnaire was distributed to members of the Analytical Laboratory Manager's Association (ALMA), via the Association's newsletter, in February 1996. The questionnaire is reproduced in *Appendix I*, from which it can be seen that respondents were asked for three categories of information. The first of these concerned the relative importance of 14 skills that B.S. analytical chemists might have acquired during their period of education and training. The second concerned how well prepared employers found recent B.S. hires in terms of these skills on a scale of "inadequate, adequate, superior" with some internal validation built into the survey by also allowing a response of "unnecessary." The third category of information concerned the instrumental techniques with which students should have some familiarity. The familiarity would arise from use of these instruments in an instrumental analysis laboratory class.

There does not appear to be effective communication between universities and colleges, and industry, at the level needed to make individual faculty members aware of the needs of industrial employers.

The questionnaires were analyzed by a simple numerical scoring system. For the ranking of the skills, a number was assigned to each skill according to the ranking order in the particular questionnaire. The totals for each skill were computed. For the other categories of information, the numbers of responses were totaled. In some cases, a ratio of a particular response to the total number of responses was calculated.

Results

Seventy-four questionnaires were returned; 48 were from the UMass alumni and 26 were from ALMA members. In terms of the skills that B.S. chemists should have, the results could be broken down into the four categories shown in *Table I*.

A degree of subjectivity has been introduced by labeling the categories as "most important," "very important," "important," and "not necessary." The classification of "not necessary" was validated from the responses to the questions concerning the degree of preparedness of B.S. graduates. It might also have been possible to include in this "not necessary" category skills related to information retrieval, software capabilities, and the analytical chemistry literature.

In terms of how well respondents thought B.S. chemists had been prepared, the ratio of the numbers of "unsatisfactories" to the total number of responses for a particular skill was computed. Those skills for which this ratio exceeded 0.30 are listed in *Table II* in the same categories as were identified in Table I.

The skills that received the highest inadequacy rating were as follows: knowledge of safe working practices, knowledge of appropriate statistical procedures, understanding the scope and limitations of instruments, and ability to communicate in writing. In addition, respondents indicated that students' skills in the areas of time management, knowledge of sample preparation procedures, and automation of analytical methods were inadequate. On the other hand, the inadequacy ratio for the ability to work as a team member was 0.14; for quantitative laboratory skills (use of calibrated glassware, etc.) it was 0.17, and for knowledge of software capabilities it was 0.25. These three skills

Table I

Ranking order of 14 skills based on 74 responses to questionnaire

Category 1: Most important	*Category 2: Very important*
Work as a team member	Safe working practices
Solve problems	Operate some instruments
Communicate orally	Understanding principles of instruments
	Knowledge of scope and limitations of instruments
	Write reports
Category 3: Important	*Category 4: Not necessary*
Knowledge of statistical procedures	Program in a high-level language
Awareness of analytical chemistry literature	Use mainframes
Awareness of software capabilities	
Information retrieval	

Table II

Skills in which recent graduates were considered inadequate

Category 1: Most important	*Category 2: Very important*
Solve problems	Safe working practices
Communicate orally	Understanding principles of instruments
	Knowledge of scope and limitations of instruments
	Written communications
Category 3: Important	
Knowledge of statistical procedures	
Information retrieval	

Table III

Instruments with which students should have operating experience

Group 1

UV-VIS absorption spectrometer, potentiometer (pH measurement), gas chromatograph, high-performance liquid chromatograph, infrared absorption spectrometer, atomic absorption spectrometer, autotitrator

Group 2

Mass spectrometer, thermal analyzer, electrochemical analyzer, optical microscope, atomic emission spectrometer, CHN analyzer

Group 3

Nuclear magnetic resonance spectrometer, molecular fluorescence spectrometer

Table IV

Comments by respondents

"There are problems with the ability to read and understand technical manuals."

"It is far more important that chemists understand a reaction or measurement and how to make that meaningful than it is for them to know programming or software."

"Graduating chemists should be able to perform routine laboratory operations in a safe and knowledgeable manner."

"Of prime importance is a basic knowledge of chemistry and the ability to apply it to industrial chemicals. Most B.S. chemists we have hired had difficulty relating classroom chemistry to daily industrial chemistry."

"All graduates should get involved in co-op positions. Profs. should get involved in industry. Colleges are too isolated from reality."

"The most important characteristic of a graduate chemist is a love of chemistry."

also received a significant number of "superior" ratings (the corresponding ratios being 0.08, 0.11, and 0.14, respectively).

The results of responses to the question concerning which instrumental techniques B.S. chemists should have some direct experience with are summarized in *Table III*. The techniques are broadly grouped into three categories, which might be classified as "absolutely necessary," "highly desirable," and "not necessary," based on the numerical scores that each received.

Several respondents offered some additional comments. These are summarized in *Table IV*. Respondents also indicated that nearly all employers provided training for newly hired B.S. graduates and all employers offered continuing education opportunities.

Respondents indicated that students' skills in the areas of time management, knowledge of sample preparation procedures, and automation of analytical methods were inadequate.

Validation of results

There is a possible problem with the methodology used to gather information for this study (and others like it): Questionnaires may only be returned by those who have adverse criticisms to make, and therefore the views expressed by the respondents may not be representative of employers of B.S. chemists as a whole. By analogy with the validation of an analytical chemistry method, one procedure that can be invoked is the examination of the results of other procedures (assuming these to be valid). There are several other sources of information that can be examined to see how the results compare.

Table V
Qualities U.K. employers seek in graduate analytical chemists

1. *Professional*
   - Problem-solving abilities
   - Ability to think logically scientifically and critically
   - Knowledge of basic chemistry
   - Appreciation and understanding of quality assurance
   - Ability to work independently and in a team
   - Understanding of the meaning of the result
   - Good manual dexterity
   - Data handling/computer skills
2. *Personal*
   - Well organized, methodical. flexible. able to follow instructions, question what he/she is doing, shows initiative. good presentational skills, pays attention to details

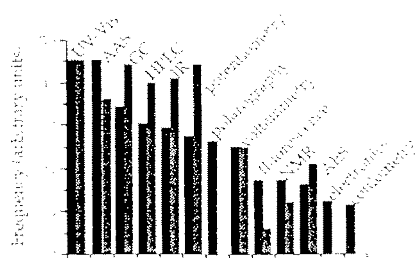

Figure 1 ■ *The 13 techniques that appeared most frequently in the laboratory portion of instrumental laboratory courses.* ▪ *The same techniques scaled according to the requirements of industrial employees.*

In 1992, the comments made by some of the members of the Industrial Advisory Board of the Chemistry Department of the University of Missouri—St. Louis, when asked "for input concerning the preferred content of analytical chemistry courses," were published.[3] The responses from the Advisory Board Members indicated that they did not expect B.S. chemistry majors to have been "trained" to operate the instruments in industrial laboratories. Instead, they looked for students with various basic skills and preferred that students were helped to do the following: develop good quantitative work habits, master report writing, understand analysis assessment, grasp the principles of the techniques, and acquire some experience with the more modern methods. These skills may readily be identified and matched with the skills listed in Table I.

The instrumental techniques that were specifically mentioned were HPLC, GC, and IR and UV-VIS spectrophotometry. These techniques are all group 1 techniques in Table III.

The corresponding situation in the U.K. was recently summarized by Fleming and Sargent,[4] and it appears that the situation there is far from satisfactory.[5,6]

The results of these surveys show that some curriculum revision is in order.

In reporting the results of an extensive survey of employers of analytical chemists in U.K. industry, "about 50% of those questioned were critical of the quality of education provided by full-time broad-based chemistry degree courses" and the authors concluded that "it seems to us that the education provided by the majority of U.K. chemistry departments is heavily biased toward the relatively small minority of students who will become research chemists." It is important to note that the survey did not simply rely on the returns of a questionnaire survey (60 returns out of 200 sent out), but also involved in-depth interviews with a variety of personnel at up to five different levels of seniority from 14 large employers of analytical chemists. The qualities that U.K. employers of B.S. chemists are seeking are summarized in *Table V* and, once again, these may be readily correlated with those in Table I and with the statements made by the members of the Industrial Advisory Board of the University of Missouri—St. Louis.

There would appear to be good agreement among all three sources with regard to the qualities and skills that employers of B.S. chemists are looking for. There is good agreement in terms of statements concerning instrumental techniques that graduates should be familiar with. There is, therefore, a sound basis for believing that the level of dissatisfaction expressed by the respondents of the surveys in both the U.S. and the U.K. is representative of the feelings of all employers.

Instrumental topics

There is one further comparison that can be made between what industry is asking for and what institutions of higher education are providing, and that relates to the topics covered in the instrumental laboratory class. Harris and O'Brien[3] surveyed a number of chemistry departments concerning the content of their instrumental analysis courses (70 questionnaires were sent out of which 32 were returned). The results are shown in *Figure 1*. Also shown in Figure 1 are the relative rankings of the various techniques listed in Table III, scaled so that UV-VIS spectrophotometry, the technique with the highest ranking, has a score of 45. It may be seen from a comparison of the lengths of the bars that students are exposed to too much electrochemistry and not enough spectrometry and chromatography.

Discussion

Clearly, the results of these surveys show that some curriculum revision is in order if the needs and wishes of employers of B.S. chemists are to be taken into consideration. Some of the deficiencies may be considered inherent in the curriculum as a whole, not just within the confines of analytical chemistry. Thus, topics such as problem-solving, oral and written communications skills, and knowledge of safe working practices should be addressed by all faculty who teach chemistry students. Maybe chemistry departments should be looking for some help from departments that have specific expertise in, for example, the teaching of logic, and of communications skills. It is interesting to note that the skills considered most important by industrial employers (and the ones for which student preparation was identified as being the poorest) are skills that might also be considered relevant in the preparation of students for graduate study. It might be concluded that the development of these skills is neglected because the curriculum is filled with other material directly related to the acquisition of knowledge of chemical facts and theories.

However, it is clear that some of the deficiencies in the preparation of students for employment as analytical chemists are to be laid at the door of the analytical chemistry courses in the undergraduate program. From the information gathered in the UMass survey, it appears that these deficiencies are related to instrumental methods, statistical evaluation of data, sample preparation, and automation. The main deficiencies identified related to students' awareness of the performance of chemical instrumentation. Institutes of higher education should examine how this material is taught. The information in Figure 1 can be taken as a starting point in terms of course content.

Part of the difficulty of curriculum reform in the U.S. higher education system is the overreliance on the "one-course-per-semester-taught-by-one-faculty-member-using-a-standard-text" format. This format has a number of positive features (it allows prolonged contact between the instructor and the students, permits innovative teaching methods to be used, and allows for flexibility in the course content), but it also has disadvantages. In reality, the course syllabus is often dictated entirely by the course text. Textbooks are not written by research-active academics in collaboration with industrial analytical chemists, and so the contents do not reflect the current practice of analytical chemistry. Since the early development of analytical chemistry within higher education in the U.S. was perpetrated by electrochemists,[7] and since there is a considerable amount of inertia associated with textbook contents, electrochemistry now occupies a greater proportion of the analytical chemistry syllabus than it should. The amount of time allocated to instrumental topics may be inappropriate if "instrumental analysis" is a one-semester course following a one-semester course of "quantitative analysis." It might be more appropriate to split the time devoted to analytical chemistry topics to one-third "quant" and two-thirds "instrumental."

The responses from the Advisory Board Members indicated that they did not expect B.S. chemistry majors to have been "trained" to operate the instruments in industrial laboratories.

A further problem is that there are very few texts devoted to laboratory activities. In a typical course with a laboratory component, the students spend the majority of time in the lab. Unfortunately, this can be a very impoverished educational experience if the students are simply following detailed written instructions. There are some excellent suggestions for alternative ways of using the laboratory experience,[8] but the implementation of these can require an enormous amount of faculty time and effort.

Many faculty, especially those in Ph.D.-granting institutions, face the dilemma of the conscientious academic. As departments downsize, budgets are cut, and the pressure to secure external funding (for both research and teaching) increases, faculty are faced with some difficult decisions about how to allocate their time between their various teaching, research, administrative, and service commitments. As the numbers of faculty decrease, departments are likely to be less comfortable with the model that allows some faculty to be oriented primarily toward teaching than they were previously. One long-standing feature of the U.S. higher education system that mitigates the investment of faculty time in curriculum reform is the ninemonth contract. The obvious time for faculty to devote to revising teaching material is the summer period of June–August. However, since many faculty members are not paid by their institution for this period, there is an understandable reluctance on the part of research-active faculty to do anything other than research-related activities during this period.

The role of industry

Although there is the possibility of bringing some pressure to bear on institutions to consider what is taught in chemistry courses via validation by the American Chemical Society, the lines of communication are likely to be so stretched as to make a dialogue through this route largely ineffective. This is not quite the case in the U.K., where at least part of the problem resides with the fact that 1) few universities teach analytical chemistry as a coherent topic within the chemistry curriculum and 2) many chemistry departments do not have any faculty members who would consider themselves analytical chemists. There is thus the possibility that the Royal Society of Chemistry, which validates all U.K. degrees for the professional qualification of Graduate of the Royal Society of Chemistry, could insist on a certain amount of analytical chemistry in the undergraduate curriculum.

For the U.S., the most fruitful approach is to initiate dialogue at the institutional level. The following suggestions, broadly in line with those of Fleming and Sargent,[4] are made. Industry should look for ways to directly influence the educational experience of students as it relates to analytical chemistry. This can be done by making co-op and intern positions available on a regular basis. Industry should be prepared to sell the idea of the benefits of these directly to students by visiting departments and giving seminars (or contributing to teaching) and talking to students and faculty. Industry should consider donating surplus equipment for use in laboratory courses and/or undergraduate research experiences. Suggestions for ideas for these research experiences or independent studies should be made, together with offers to support projects of interest with a few hundred dollars to cover supplies. Other links with analytical chemistry faculty, such as offering a few thousand dollars on a regular basis to support relevant research by graduate students, should be considered. It is amazing how far $5000–$10,000 a year can go (it covers the summer research assistantship for a graduate student, supplies, small items of equipment, conference travel for the student, visits to and telephone calls with industrial collaborators, photocopying expenses, and so on). The institution will support the student and the project with a teaching assistantship for the student and salary for the faculty member (whom industry gets as a free consultant on the project).

If 20 companies agreed to support analytical chemistry at an institution (for example, at the University of Massachusetts at Amherst) at a rate of $10,000 per year with regular co-op and intern positions for undergraduates (and graduates), they would have a major impact on all the activities relating to analytical chemistry teaching and research in that institution's chemistry department.

Acknowledgements

The help of Shyamala Ivatury in the design, distribution, and analysis of the questionnaires sent to the University of Massachusetts alumni is gratefully acknowledged, as are all those who took the time to respond. The author is especially grateful to the Analytical Laboratory Manager's Association, whose members not only provided responses to the questionnaires, but many thoughtful and insightful comments as well.

References

1. "I Know You're a Chemist, But What Do You Do"; American Chemical Society: Washington, DC, 1996.
2. Thorpe, T. M.; Ullman, A. H. "Preparing Analytical Chemists for Industry"; *Anal. Chem. News and Features*, Aug 1, **1996,** 477A.
3. Harris, H; O'Brien, J. "Instrumental Analysis Courses Part 1. The Current Experimental Practice"; *J. Chem. Educ.* **1992;** *69*:A266.
4. Fleming, J; Sargent, M. "Chemistry graduates: How Can Industry Get What It Wants?" *Man. Mod. Lab.* **1995,** *1*:49.
5. Fleming, J; Sargent, M; Singleton, V. "Getting Our Priorities Right"; *Chem. Br.* **1994,** *30*:29.
6. Valid Analytical Measurement Viewpoint, "Education and Training of Analytical Chemists"; *Anal. Proc.* **1993,** *30*:181.
7. Murray, R. W; "Teaching of Analytical Chemistry in the U.S."; *Talanta*, **1989,** *36*:11.
8. Walters, J. P. "Role-Playing Analytical Chemistry Laboratories Part 1: Structural and Pedagogical Ideas"; *Anal. Chem.* **1991,** *63*: 977A, "Part 2: Physical Resources"; *Anal. Chem.* **1991,** *63*: 1077A. and "Part 3: Experimental Objectives and Design"; *Anal. Chem.* **1991,** *63*:1179A.

Author

Julian Tyson *is in his eighth year as a Professor of Chemistry at the University of Massachusetts, Amherst. Prior to this he was, for thirteen years, a faculty member of the Chemistry Department of the University of Technology at Loughborough in the U.K. He has taught analytical chemistry to undergraduate, master's, and Ph.D. students on both sides of the Atlantic. Influential faculty at these institutions and at Aberdeen University, Scotland (from where he obtained a B.Sc. degree), and Imperial College, London University, U.K. (from where he obtained his Ph.D.), have made him realize that chemistry is just a branch of analytical chemistry.*

Appendix I

Questionnaire sent to UMass analytical Ph.D. alumni and ALMA members

Name of Company:

Name of person completing questionnaire:

Position within organization:

1. Does your company hire graduates with a B.S. in Chemistry? Yes No

(If the answer to this is no, but your company does hire M.S. or Ph.D. graduates, it would be of interest to hear your comments concerning these, so please complete the remainder of the questionnaire.)

For questions 2-3 please use the key given and circle your response: I: inadequate; A: adequate; S: superior; U: an unnecessary skill. Add any comments you feel may be relevant to this topic.

2. Do undergraduate courses in chemistry provide students with the requisite skills in the following areas:

A. Report writing i.e. is a recent B.S. capable of producing grammatically correct, coherent and succinct prose in an appropriate style? I A S U

B. Oral communication. I A S U

C. Time management. I A S U

D. Interpersonal skills i.e. the ability to work as part of a team, the ability to interact with a diverse group of individuals. I A S U

E. Knowledge of how to perform efficient literature searches, such as the use of chemical abstracts (both on-line and in a library). I A S U

F. Knowledge of the laboratory safety procedures particularly with regard to

- the proper handling of hazardous chemicals I A S U
- the proper disposal of chemical waste I A S U

G. A knowledge of the common software to manipulate, evaluate and display data. I A S U

H. The use of molecular modelling programs and other simulations. I A S U

I. The ability to do simple programming in Basic, Fortran, C etc. I A S U

J. The ability use VAX/VMS or UNIX operating systems. I A S U

K. The ability to solve problems. I A S U

3. The Instrumental Analysis laboratory:

1. Would you expect a BS graduate to be able to use (with the aid of the operating manual) any of the following instruments? If so, please indicate which.

NMR	Y N	atomic emission	Y N
GC	Y N	pH or pIon	Y N
HPLC (incl. ion chrom.)	Y N	other electrochemical analysis	Y N
IR	Y N	automatic titration	Y N
MS	Y N	CHN analysis	Y N
AAS	Y N	thermal analysis	Y N
UV/Vis abs	Y N	optical microscopy	Y N
molec. fluorescence	Y N		

Please elaborate:-

B. What is the level of understanding of the principles of operation of the various instruments. I A S U

C. How knowledgeable are the recently hired graduates with regards to the scope and the limitations of the various common chemical instruments (such as those listed above)? I A S U

D. How knowledgeable are the recently hired graduates with regards to sample preparation and pretreatment procedures? I A S U

E. How knowledgeable are the recently hired graduates with regards to statistical procedures to evaluate the quality of quantitative data? I A S U

F. How knowledgeable are the recently hired graduates with regards to the automation of chemical procedures? I A S U

G. How would you rate the competence of new graduates to use pipets, burets, pH meters, analytical balances, perform dilutions, make standards, (i.e. the skills they might have acquired from an earlier quantitative analysis course) I A S U

4. Training

A. Does your company provide initial training for new BS graduates? Y N

If Y, please elaborate.

B. Does your company provide opportunities for continuing education (e.g. enrollment in graduate classes, workshops, short courses, conference attendance etc) to supplement the undergraduate knowledge? Y N
If Y, please elaborate.

5. Relative Importance of Skills

It is important for university educators to get some kind of picture of the relative importance of the various skills outlined earlier in this document. Please place the following in order of importance with regard to the abilities of a graduating BS chemist.

ability to write reports in appropriate format

ability to communicate orally

ability to work as a team member (interpersonal skills)

knowledge of safe working practices

knowledge of software capabilities

ability to program in some modern high level language

ability to use main frame computers

ability to operate some standard laboratory instruments

appreciation of scope and limitations of modern instrumental techniques

understanding of the principles of operation of chemical instruments

ability to apply appropriate statistical procedures to evaluate quantitative data

ability to solve problems

ability to use information retrieval facilities

awareness of the analytical chemistry literature

other: please define and rank

Comments:-

Any further comments on topics not covered by the above questions?

Many thanks for taking the time and trouble to complete this questionnaire.