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Education and Training of BS Analytical Chemists for Entry-Level Positions in Industry: A Survey

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Abstract: Surveys, in 1993 and 2003, of industrial employers of BS analytical chemists show that respondents consider employees' abilities to work as a team member, solve problems, write and communicate orally, work safely with a positive ethic, perform calculations, and apply basic chemical principles to be the most important. There is dissatisfaction with the preparation of graduates with regard to communications skills, safety training, and problem-solving abilities. Respondents also indicated that graduates should have had hands-on experience with a variety of chromatographic and spectroscopic techniques as well as some techniques not commonly encountered in the teaching laboratory, such as auto-titration, microwave digestion, and optical microscopy. Examination of recent surveys of the content of analytical chemistry courses shows a decline in the extent to which electrochemical techniques feature in the curriculum, with the possible exception of cyclic voltammetry and potentiometry, and an increase in the prominence of spectroscopy and separations, in line with the expectations of industrial employers.

Some 10,000 students graduate each year with a bachelor's degree in chemistry from just over 1,000 U.S. and Puerto Rican institutions of higher learning [1]. Approximately 50% go on to graduate or professional school of whom about 45% (i.e., 2,250) stay in chemistry [2] with about 1700 of the other 55% going to medical, dental, or pharmacy school. About 3,300 have permanent or temporary full-time jobs and 7% are unemployed. Of the 3,300 who are employed, 23% are in academia, 66% are in industry, and 12% are working for the government or other employers. This means that about 26% of B.S. graduates go directly to chemistry-related employment in manufacturing or service industries. Thus, the two destinations that take the largest fractions of new B.S. graduates are graduate school and industry; therefore, it is appropriate that the B.S. curriculum pay attention to the needs of these two destinations. While a detailed breakdown of the nature of industrial employment is not available, a significant portion of the jobs are analytical in nature [2]. In 1996, the results of a survey of employers of B.S. chemists for analytical chemistry jobs, conducted over the period July 1993 to February 1996, appeared in *Managing the Modern Laboratory* [3], the journal of the Analytical Laboratory Managers' Association (ALMA). At that time, there was considerable interest in the training of B.S. analytical chemists in both the U.S. and the U.K. In the U.S., the papers presented at the Education for Industry symposium at the 212th ACS National Meeting (August 1996) were published [4], and the deliberations and conclusions of workshops, sponsored by NSF's Divisions of Chemistry and Undergraduate Education, held in October 1996 and March 1997 also became available under the title "Curricular Developments in the Analytical Sciences" [5]. In the U.K., the Laboratory of the Government Chemist had, in 1993, issued a report of the results of a comprehensive survey of industrial employers of B.Sc. graduates for analytical chemistry jobs entitled "Study on the Supply and Demand for Analytical Chemists" [6]. he contents of the report were described in a 1995 article in *Managing the Modern Laboratory,* entitled "Chemistry Graduates: How Can Industry Get What it Wants?" [7].

Common to the surveys on either side of the Atlantic was the general finding that there was considerable dissatisfaction with the state of preparation of students for work as analytical chemists. In the U.S., considerable efforts were made by several educators who had been participants in the NSF workshops to spread the word about the need for curricular reform in the teaching of analytical chemistry and to provide resources to facilitate such reform and implement new pedagogies [8–10]. Such efforts included a series of conference symposia at, for example, the Federation of Analytical Chemistry and Spectroscopy Societies (FACSS) annual meeting, as well as workshops on problem-based learning at the annual Pittsburgh Conference and Exposition and a series of articles in the A-pages of *Analytical Chemistry* [11–13]. These initiatives were also responsible, in part, for the creation of the Analytical Sciences Digital Library [14].

There does not seem to be much discussion in the chemical education literature over the preparation of B.S. chemists for employment in U.S. industry: a search of the literature turned up only one or two articles. In 1999, Tolman and Parshall [15] identified some 50-year trends in the chemical industry and indicated that the qualities that chemical companies seek in chemists and technicians include the abilities to (a) work creatively on complex and unfamiliar problems, (b) communicate effectively in both speaking and writing, (c) work in teams and (d) assess one's own knowledge and learn what one needs to know over the course of one's entire career. In addition, they wrote that "technicians need to understand basic chemistry, physics, biology, mathematics, and computer operations. Communications skills, both oral and written are now important." In 2001, Marine [16] reported on the teaching of workplace skills in a simulated analytical department. The program was designed "to teach laboratory skills, communication skills, computer skills, and workplace factors such as teamwork and ethics." In a later report [17], an

Table 1. Ranking Order of 14 Skills Based on 33 Responses to Questionnaire

Category 1: Most important	Category 2: Very important	Category 3: Important	Category 4: Not necessary
Work as a team member	Operate some instruments	Knowledge of statistical procedures.	Program in a high-level language
Solve problems	Understanding principles of instruments.	Awareness of analytical chemistry literature	Use main-frames
Communicate orally	Knowledge of scope and limitations of instruments.	Awareness of software capabilities	
Written communication skills	Ability to work independently	Information retrieval	
Positive work ethic	Multi task	Knowledge of a second language	
Safe working practices	Ability to perform quantitative manipulations	Knowledge of QA/QC and FDA/EPA regulations	
Basic chemical principles			
Ability to perform basic calculations			

approach to the acquisition of experimental design and critical thinking skills through participation in “reiterative lab projects” was described and evaluated. This lack of discussion in the original literature is probably not a cause for concern as the ACS Committee on Professional Training has provided [18] a comprehensive commentary on curriculum requirements as well as setting out some specific requirements for content, equipment, and instrumentation.

A follow-up survey of the same databases of participants in our 1993 survey [3] has been carried out. Newly hired B.S. chemists were also asked to participate via a separate questionnaire. The follow-up survey asked employers to examine the ranking order of knowledge and know-how that was drawn up as a result of the first survey and to make any changes they thought appropriate. They were then asked to comment on the state of preparation of recent B.S. hires with respect to these topics. Employers were also asked to express an opinion on the content of an instrumental analysis course in terms of some broad categories such as (a) instrumental techniques to be included, (b) statistical evaluation of data, (c) sample preparation, and (d) automation of measurement procedures. Employers were also asked to comment on more general goals of an undergraduate chemistry program, such as the acquisition of knowledge of safe working practices, time management skills, written and oral communication skills, and interpersonal skills

In this paper, we present the results of the 2003 survey, together with a comparison with the results of the 1993 survey and some evaluative commentary. A small number of responses were received from newly hired B.S. chemists, and some of the respondents’ comments are also presented (in the supplemental material).

Experimental

The first (1993) survey of employers was performed in two stages: in stage one, 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), Respondents were asked for three categories of information: first, the relative importance of 14 skills that B.S. analytical chemists might have acquired during their period of education and training; second, how well prepared did employers find 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;” and third, what were the instrumental techniques with which students should have some familiarity arising from use of these instruments in an instrumental analysis laboratory class. In the follow-up survey of November 2003, a slightly revised questionnaire was sent (by electronic mail) to a somewhat smaller number of these two categories of employers. Both questionnaires are available as supplemental material.

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.

A survey was also distributed via the employer respondents to B.S. employees. This survey is also available as supplemental material.

Results

For the original survey, 74 questionnaires were returned. The numbers sent to ALMA members was not known, but the return rate from the UMass alumni was 37%. In the follow-up survey 34 were returned; again, the number sent to ALMA members is not known, and the return rate from the UMass alumni was 38%. The skills that employers expect B.S. chemists to have are divided into four categories shown in Table 1.

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. Since the first survey, there have been a number of changes: the most important category has been increased by the inclusion of “written communication skills” and “knowledge of safe working practices” (both moved up from the second category) as well as “positive work ethic,” “basic chemical principles,” and “ability to perform basic calculations,” four skills that were not explicitly listed in the results of the first survey. The “very important” category has been augmented by the inclusion of “ability to work independently,” “ability to multi-task,” and “ability to perform quantitative manipulations.”

The important category has been augmented by “knowledge of a second language” and “knowledge of QA/QC protocols and FDA/EPA regulations.” There was no change in the contents of the “not necessary” category.

In terms of how well respondents thought B.S. chemists had been prepared, the ratio of the numbers of "unsatisfactory" responses 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 2 in the same categories as were identified in Table 1. The numbers in parenthesis are the fraction of the respondents giving a rating of “unsatisfactory.” The first number is for the 1996 survey and the second number is for the 2003 survey (where only one number is given, this refers to the 2003 survey). The skills that received the highest inadequacy

Table 2. Skills in Which Recent Graduates Were Considered Inadequate

Category 1: Most important	Category 2: Very important	Category 3: Important
Solve problems (0.42, 0.45)	Knowledge of scope and limitations of instruments (0.57, 0.48)	Knowledge of statistical procedures (0.56, 0.45)
Communicate orally (0.37, 0.39)		Information retrieval (0.35, 0.21)
Safe working practices (0.60, 0.42)		
Written communication (0.49, 0.39)		

Table 3. Techniques for Which Students Should Have Operating Experience

Group 1 (> 66%)	Group 2 (33–66%)	Group 3 (< 33%)
Infra-red absorption spectrometry (100)	Mass spectrometry (42)	Inductively coupled plasma -optical emission spectrometry (30)
pH measurement (100)	Optical microscopy (55)	Nuclear magnetic resonance spectrometry (30)
UV-visible absorption spectrometry (97)	Flame atomic emission spectrometry (45)	Thermal methods (30)
Gas chromatography (97)	Microwave digestion (33)	Electrochemical techniques (30)
High performance liquid chromatography (94)	X-ray fluorescence spectrometry (33)	CHN analyzer (21)
Atomic absorption spectrometry (73)		Molecular fluorescence spectrometry (24)
Auto-titration (73)		Inductively coupled plasma -mass spectrometry (15)
		Surface analysis (21)
		Gel (18) and capillary electrophoresis (21)

ratings were as follows: knowledge of safe disposal of hazardous waste (0.60, 0.42), knowledge of sample preparation procedures (0.64. 0.54), knowledge of appropriate statistical procedures (0.56, 0.45), the use of molecular modeling and other simulation software (0.48), and the ability to communicate in writing (0.49, 0.39).

In addition, respondents indicated that students' time-management abilities, interpersonal skills, and knowledge of the automation of analytical methods were inadequate. The responses obtained indicate that there has been little change in the perception of employers who responded since the earlier surveys of approximately 10 years ago. Although employers are more satisfied with the preparation of graduates in terms of their ability to understand the principles of various instrumental techniques, there was still considerable dissatisfaction expressed. Respondents indicated that they considered students to be adequately prepared in terms of quantitative laboratory skills (use of calibrated glassware, etc.), and in their knowledge of "common" software. These two skills also received a significant number of "superior" ratings (the corresponding ratios being 0.36 and 0.54, respectively).

The instrumental techniques with which BS chemists should have some direct experience are summarized in Table 3.

The techniques are broadly grouped into three categories based on the percentages of respondents who answered "yes" when asked if students should have had hands-on experience with that particular technique. These percentages are given in parentheses in the table. Compared with results of the earlier survey, there is no change in the techniques that get the highest ranking; however, respondents considered thermal analysis, CHN analysis, and electrochemical analysis (apart from potentiometry) to be less important than 10 years ago as these techniques are now assigned to Group 3 rather than Group 2. A number of techniques not mentioned 10 years ago now appear in Group 3: inductively coupled plasma mass spectrometry (ICP–MS), ICP optical emission spectrometry, surface analysis, and capillary and gel electrophoresis. Several employers offered some additional comments. These are summarized in the supplemental material. Respondents also indicated that nearly all employers provide training for newly hired BS graduates, and all employers offer continuing education opportunities.

Reponses were received from a limited number of recent B.S. employees. While these may not be representative, they are provided in the supplemental material as they indicate a considerable difference in perception over the issues of problem-solving and communication skills, in that the recent graduates feel they were well prepared. We consider that further surveys of a greater number of graduates over increasing periods since graduation would be of interest, and is perhaps something that might fall within the remit of the ACS Committee on Professional Training.

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.

Taking the issue of what is regarded as the relative importance of various skills and content knowledge first. In 1992, comments made by some of the members of the Industrial Advisory Board of the Chemistry Department of the University Missouri, St. Louis, when asked "for input concerning the preferred content of analytical chemistry courses," indicated [19] 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, and 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 1 above. Further validation may be obtained from an examination of the guidelines set out by the Committee on Professional Training of the American Chemical Society [18]: “A strength of chemistry as general education as well as professional training is that problem-solving skills are emphasized and developed...of comparable importance to problem solving is effective communication through writing and speaking.” With regard to the validity of the extent to which recent graduates demonstrate satisfactory acquisition of these abilities, there are few comparative data available. In the report of the NSF workshops on curricular reform in the analytical sciences [5], the following statements appear: “Industry representatives and educators lamented the fact that students also needed to improve their skills in communication, teamwork, and problem-solving." and "A growing number of new hires lack the technical and personal skills industry needs.”

It is also of interest to examine the extent to which there is agreement between what industrial employers indicate they want in familiarity with instrumental techniques (see Table 3) and the extent to which these techniques are covered in the laboratory experience. The instrumental techniques that were specifically mentioned by members of the Industrial Advisory Board of the Chemistry Department of the University Missouri, St. Louis were HPLC, GC, and IR and UV–vis spectrophotometry. These techniques are all Group 1 techniques in Table 3. A survey of practicing analytical chemists within Merck [20] produced the consensus that “basic analytical techniques should be taught as early as possible in high school and undergraduate courses.” They also agreed that “laboratory courses in qualitative and quantitative analysis are essential” and that important ingredients in the undergraduate curriculum were “spectroscopy, separation science, electrochemistry, experimental design and statistics, and electronics for chemists.” Responders to the Merck survey also expressed the opinion that “undergraduates don’t have access to modern analytical instruments even in schools that have these instruments.” The ACS Committee on Professional Training indicates that “laboratory instruction should include practical experience with instrumentation for spectroscopy, chemical separations, and electrochemistry” and that the experience should give students the “self-confidence and competence to...use and understand modern instruments particularly NMR, Fourier transform (FT)–IR, and UV–vis spectrometers; GC, GC–MS, and HPLC instruments for chemical separations; and electrochemical instruments.”

In 2000, Girard and Diamant presented [21] the results of a 1998 survey of the topics taught in instrumental analysis lecture and laboratory courses. They compared their results with those of a 1981 survey by Sherren, whose results were only disclosed at a Regional ACS meeting [22]. In 2002, Mabrouk presented [23] a thoughtful analysis of both the characteristics of the faculty teaching the undergraduate quantitative analysis course and of the courses themselves. Their results also showed that “instrumental” topics are now being taught in the “first semester quantitative” course. This strongly suggests that to get a meaningful picture of what analytical chemistry topics are being taught in colleges and universities, it will be necessary to survey both courses at any particular institution, together with a question about how many students take both courses.

From the results of our earlier survey, it was concluded that from industry’s perspective too much electrochemistry and not enough spectroscopy and chromatography were being taught [3]. Girard and Diamant and Mabrouk indicate that there has been a noticeable shift in the topics taught to bring them more in line with what industry is looking for. Girard and Diamant show [21] that the extent to which electrochemistry techniques are featured in the instrumental analysis laboratory has decreased for all electrochemical techniques except cyclic voltammetry (CV), whereas spectroscopic and instrumental chromatographic techniques (including capillary electrophoresis) are featured to a greater extent. There is still some ambiguity over the importance of potentiometry and CV. The issue of CV maybe reflects an increased use of this technique in faculty research laboratories as a probe of reaction mechanisms. Perhaps more serious is the view that industrial respondents have of the importance of optical microscopy, which appears to be taught nowhere in the analytical courses, and of the value of experiences with an auto-titrator, microwave-assisted digestion, and mass spectrometry (other than as a GC detector). This raises questions as to whether the analytical chemistry curriculum should include topics relevant to (a) the automation of chemical measurement procedures, which might also include flow injection and continuous flow techniques, and (b) sample preparation procedures, which might include crushing, grinding, dry ashing, Soxhlet extraction, and pressurized solvent extraction. Finally, there is the issue of to what extent do chemistry courses deal with relevant (i.e., analytical) aspects of MS, NMR, and IR in courses other than analytical courses. Girard and Diamant [21] write “although most instructors include GC and proton NMR in their [instrumental analysis] courses, these topics were taught by fewer instructors in 1998 than in 1981. As Organic Chemistry II has become more a spectroscopy course, these techniques are generally being taught in the sophomore year.” This seems to be a timely topic in the light of the considerable rise in importance of mass spectrometry in many areas of chemistry and is the subject of a recent survey of college and university chemistry departments [24].

Discussion

It would appear that although there have been changes in the content of instrumental analysis and quantitative analysis courses in recent years, some employers of B.S. chemists for analytical positions are still dissatisfied with the preparation of students. While it is possible that no matter what curriculum revisions are implemented, this will always be the case, we think that it is worth examining the comments from the limited number of respondents. Some of the possible deficiencies identified may be considered the responsibility of the curriculum as a whole and not just the responsibility of analytical chemistry. Thus, topics such as problem-solving, oral and written communication skills, and knowledge of safe working practices should be addressed by all faculty who teach chemistry students. 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. Could it be that these skills are neglected because the curriculum consists of material directly related to the acquisition of knowledge of chemical facts and theories? Teaching problem-solving skills requires considerable shifts in the pedagogical paradigm, so that students participate in more problem-based learning (PBL) activities. Although Wenzel has written extensively about the benefits of PBL, it seems that there is little material available to help faculty [13] and that at present not all faculty are supportive of this approach. Mabrouk found [23] that although 44% of faculty teaching quantitative analysis use PBL in their classrooms, 45% were neutral on the issue of whether PBL was "simply an educational fad." We encourage the community to be active in developing and disseminating curricular materials related to problem-based learning. Teaching written communication skills consumes a lot of faculty time, as the only way to do it effectively is to give students feedback on their writing at the mid-process draft (the student's best effort) stage so that he or she can revise the piece before it is graded. The chemical education literature does address the integration of writing into the chemistry curriculum [25–27]. Faculty who have responsibility for undergraduate student researchers have the opportunity to provide effective feedback to students in relation to project reports and poster presentations; therefore we recommend that all such REU-type activities incorporate written and oral communication components with timely feedback from the faculty adviser. We also propose that research experiences be incorporated into the early stages of curriculum and not left until the junior or senior year.

It is clear that some of the issues perceived by the respondents in the preparation of students for employment as analytical chemists (see Table 2) are to be laid at the door of the analytical chemistry courses in the undergraduate program. These possible deficiencies are related to how chemical instruments work and the scope and limitations of procedures in which instruments are used, statistical evaluation of data, sample preparation, and automation. Since the first survey, there would seem to be an improvement in the match between the techniques that industrial employers think that students should be exposed to in terms of the relative amounts of spectroscopy, chromatography, and electrochemistry. It is not clear where the measurement of pH is taught (a high priority for industrial employers), and it appears that students are not given the opportunity to use an autotitrator, a microwave oven, an optical microscope, or an X-ray fluorescence spectrometer, all of which are considered desirable by industrial employers. Clearly it is not possible for the typical undergraduate courses to provide hands-on experience with all of these instruments and allow students the opportunity to engage in problem-based learning, and so instructors have to make choices about what to leave out. We suggest that the more instrumentation students experience directly, the more comfortable they will be in dealing with unfamiliar instruments in their first employer's laboratory. Students should make instrumental measurements as early as their introductory chemistry laboratory and, as mentioned earlier, should be making instrumental measurements in their independent research experiences at the earliest opportunity.

The Role of Industry

It appears that there is good agreement between what industry would like to see students learn at the B.S. level and what the ACS Committee on Professional Training says should be taught. As the present reality appears to be that, according to some respondents, institutions are "failing to deliver," maybe there is a role for direct interaction between industrial organizations and chemistry departments. The following suggestions, broadly in line with those of the NSF workshop report [20], are made. Industry should look for ways to influence the educational experience of students directly. This can be done by making co-op and intern positions available on a regular basis. Industry should be prepared to sell the benefits of such positions directly to students by visiting departments and giving seminars, contributing to teaching, and talking to students and faculty. Industry should consider (a) donating surplus equipment for use in laboratory courses and/or undergraduate research experiences, and (b) providing ideas for these research experiences.

Having urged industrial organizations to be more aggressive in seeking contacts with chemistry departments, it is also appropriate to suggest that chemistry departments be proactive in seeking industrial input to discussions of curricular developments by, for example, the creation of Industrial Advisory Boards. It should not be too difficult to persuade a limited number of alumni now holding senior positions in industry to serve in this capacity. We suggest that faculty advisers should also be encouraging students to get industrial experience as part of their undergraduate education and training.

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Supporting Materials. The original and follow-up employer questionnaires, the employee questionnaire, and some individual comments by employers and recently hired B.S. graduates are available as supporting material (http://dx.doi.org/10.1333/s00897061077a).

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