GRADUATE EDUCATION IN CHEMISTRY

The ACS Committee on Professional Training: Surveys of Programs and Participants

ACKNOWLEDGMENTS

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Graduate Education in Chemistry

The ACS Committee on Professional Training: Surveys of Programs and Participants

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Executive Summary

Graduate Education in Chemistry in the United States: A Snapshot from the Late Twentieth Century

Included in this booklet are four reports concerning graduate education in chemistry published between 1997 and 2000. These reports seek to illuminate the nature of our graduate programs and the opinions of the graduates of those programs. The underlying motivation is to provide data that will serve as valuable input to chemistry faculties and others who are striving to provide the best and most relevant graduate education that is possible.

The reports are the results of three surveys that were conceived, carried out and analyzed by the Committee on Professional Training (CPT) of the American Chemical Society (ACS). The general charge of CPT is to examine chemical education in the United States at the postsecondary level. CPT is well known for its involvement with baccalaureate programs in chemistry and has operated a certification program for bachelor's degree graduates for over sixty years. The role of CPT in graduate education has focused on providing reports about trends and practices in M.S. and Ph.D. programs in the United States to the chemical community. A new round of study and evaluation began in 1996, which resulted in the reports listed below.

What will you find in these four reports?

• **What's going on in the Ph.D. programs in chemistry?** The first report arose from a 1996 survey of 190 Ph.D. programs in which the institutions were asked to report their current requirements and other features of the Ph.D. program. Whether you are interested in the fraction of programs with a foreign language requirement or the size distribution of Ph.D. programs, the first report is the place to turn for answers.

• **What about the M.S. programs in chemistry?** CPT also surveyed programs offering the M.S. degree. The results are summarized in the second report where you will learn of the great diversity of programs that exists, the clientele of those programs and specific examples of programs with focused objectives and requirements.

• **Are the graduates of Ph.D. programs satisfied with the education they received?** In this report you will learn of the results of a survey of 4000 randomly selected ACS members who hold the Ph.D. degree. This survey was conducted in 1998 and the results are reported in the third and fourth reports. The third report contains a statistical analysis of twenty-six questions for which numerical responses were requested. The fourth report, a more personalized document, analyzes the written comments of the respondents.

In the third report, you will learn what graduates think about course requirements, cumulative examinations, the effectiveness of the research advisor and interdisciplinary research to name a few topics. Comparisons are made between male and female chemists, those who received the degree (on average) in 1981 with those who graduated a decade later, and finally and most revealingly, a comparison of the opinions of those working in industry with those in academia.

• **What are the Ph.D. graduates really saying?** In the last report, the almost one thousand written comments from the survey of Ph.D. recipients are analyzed. Whether short or lengthy, all the comments were categorized and sorted. Are those working in industry pleased with their preparation? Turn here for an answer. What categories drew the largest number of comments? How have the concerns changed since CPT's earliest reports on Ph.D. education? We are confident that the answers to these and other questions will stimulate your thinking. Add to this about fifteen specific quotations from the comments and a list of suggestions for improvements and you have the makings of an interesting reading session.

*Survey of Ph.D. Programs in Chemistry**

The principal emphasis of CPT has always been on undergraduate education in chemistry, but the responsibility of monitoring and evaluating graduate education also falls within its purview. Recently, concerns have been expressed about the health of our graduate programs, in response to which ACS president Ronald C. Breslow convened a conference at Columbia University in November 1995 to discuss the present state of Ph.D. education in chemistry. Arising from the discussion at that conference was a list of desirable qualities for a good Ph.D. program, and these were reported in an ACS Comment by President Breslow that appeared in *C&EN* (December 11, 1995, pp 65–66).

At this point it became apparent that it would be highly desirable to determine just what the current practices are among the 190 Ph.D. programs in chemistry that are known to CPT. Thus, in cooperation with President Breslow, CPT composed and distributed a questionnaire, which was mailed to all the Ph.D. programs in May 1996. By late summer, responses had been received from 155 of these programs and CPT was able to present a preliminary analysis of the data at the Presidential Event, "Graduate Education in Chemistry—Are Changes Needed?", which was held at the 212th ACS National Meeting in Orlando. This preliminary analysis will be presented here in somewhat greater detail. An analogous survey of master's degree programs has been conducted, and the results will be published at a later time.

Results of survey of Ph.D. programs in chemistry. The results are summarized in Table 1 where averages of the responses are reported. There are two averages. The first is simply the sum of the responses divided by the number of reporting programs. The second is a weighted average in which the response for each school is multiplied by the number of students in that program, a sum is taken over all of the schools and that sum is divided by the total number of students. The weighted average provides an indication of whether or not a given practice is more prevalent in the larger programs. For example, 19% of the programs have a foreign language requirement (unweighted average) while the weighted average response was 15%. Thus, only 15% of the students are in programs that have a language requirement whereas 19% of the schools have such a requirement. Thus, it is probably true that larger schools are less likely to have a language requirement than are the smaller programs. Both weighted and unweighted averages are provided in the Table, but only unweighted averages will be discussed in what follows.

General features of Ph.D. programs in chemistry. There is a tremendous range in size of Ph.D. programs—from 3 to 338 students for the 155 reporting schools (see Figure 1). The 30 largest schools enroll almost half of the chemistry Ph.D. students in the reporting programs. There are also many smaller Ph.D. programs with about 50 institutions reporting fewer than 50 students. The average program size is 84 students and the average size of the graduate faculty is 22. Students in Ph.D. programs are supported in a variety of ways. The schools were asked what fraction of graduate student support was in the form of teaching assistantships, and the average of the reporting schools was 50%. The average percent support from faculty-generated research funds was 38%, university or departmental fellowships 7%, government fellowships 4%, with other sources making up the difference. The departments reported that an average of 7% of the total graduate student support comes from industry.

Educational breadth of the Ph.D. program. Participants in the Columbia conference felt that in addition to developing a mastery of a specific area of chemistry, students should take a significant fraction of courses outside their area and participate in other activities to provide educational breadth. Some of the questions asked of the Ph.D. departments were related to this issue.

Of the reporting schools, 81% require placement examinations to judge the breadth and soundness of the undergraduate training. The schools reported that on average Ph.D. students take 22 semester credit hours of course work and 37% of these are outside the student's area of specialization. The survey found that 96% of the schools have department-wide colloquia, which include speakers from a variety of areas. On average, the schools estimated that 57% of the individuals attending these colloquia were from outside the area of the speaker. The schools also reported that 16% of their colloquium speakers were from industry.

About 17% of Ph.D. graduate students in chemistry participate in interdisciplinary programs involving other departments, and 26% of the programs allow or require students to spend short periods of time in several laboratories before selecting a research advisor. All of these questions shed some light on the breadth of the educational experience.

Development of communication skills and creative thinking. This was identified as one of the crucial components of a strong Ph.D. program. When asked how many oral presentations a student made during

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the course of Ph.D. study (other than those made to the student's own research group), the schools reported an average of 2.8. Almost all graduate students (93%) are reported to serve as teaching assistants sometime during the Ph.D. program, but of these only 40% taught discussion sections which, unlike laboratory sections, are highly likely to involve a formal oral presentation.

The creation and defense of one or more original research proposals was a required feature of 84% of the programs, while the requirement of a final oral presentation of the thesis was almost universal (92%).

These responses reveal some of the ways that development of communication skills and creative thinking are being encouraged in Ph.D. programs in chemistry.

Other requirements. Cumulative examinations are required by 73% of the reporting schools, 53% require an oral preliminary examination, 33% require a comprehensive written examination, and 44% indicate that a comprehensive oral examination is a part of the Ph.D. program. The foreign language requirement now exists in only 19% of the schools. The practice of naming an advisory committee to monitor the progress of the Ph.D. student is followed by 89% of the programs.

The survey revealed that 68% of the departments put an upper limit on the time permitted for achieving the Ph.D. degree, and the average upper limit was 7.2 years. Also, about two-thirds (71%) of the programs put a limit on the number of years of financial support that a Ph.D. student can receive, and the average limit is 5.5 years. Finally, the schools reported that an average of 5.1 years was required for their students to complete the Ph.D.

Summary. This analysis of the survey data provides a general picture of the shape and dimensions of Ph.D. education in chemistry as practiced in the graduate schools of the United States. After learning what the average requirements and practices are in our graduate programs, we can begin the more important task of formulating answers to the question raised in President Breslow's Presidential Event: "Graduate Education in Chemistry—Are Changes Needed?"

Figure 1. Size distribution of Ph.D. programs

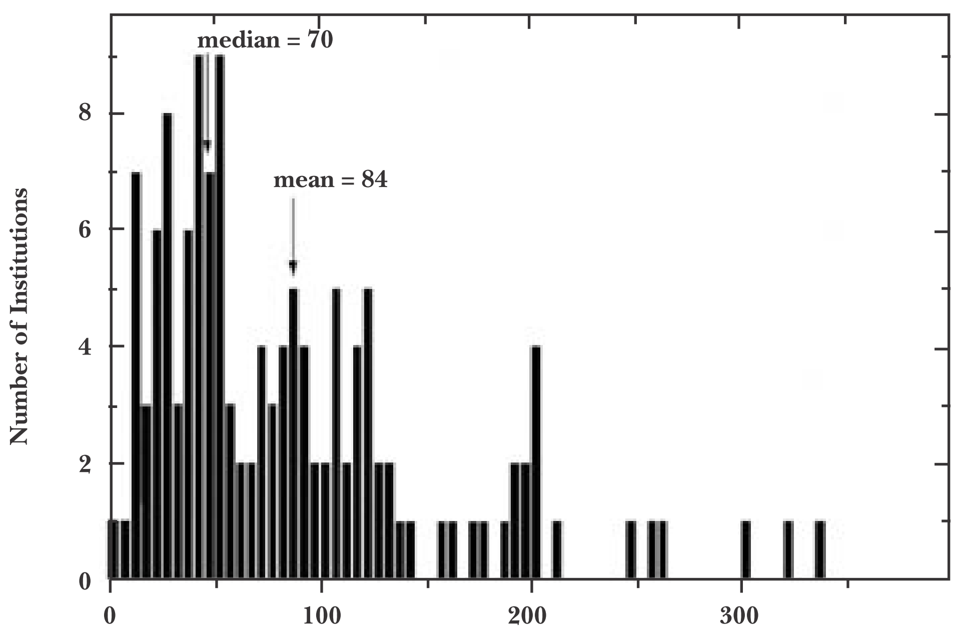

Table 1. Results of Survey of Ph.D. Programs in Chemistry[a]

Question		Average[b] Unweighted	Weighted
1. Number of graduate students in the Ph.D. program		84	[c]
Number of graduate faculty		22	[c]
2. Do your entering graduate students have to take placement exams to determine their preparation for graduate study?	Yes	81%	77%
	No	19%	23%
If so, are there programs designed to correct any deficiencies detected?	Yes	88%	85%
	No	12%	15%
3. How many semester credit hours do your students typically spend in formal graduate courses, not including research and seminar?		22 hr	22 hr
4. Approximately what percentage of the courses are taken outside the student's own field, e.g., organic chemistry?		37%	34%
5. Do you have regular department-wide colloquia?	Yes	96%	93%
	No	4%	7%
If so, approximately what percentage of those attending are from outside the field of the speaker?		57%	51%
What percentage of the speakers come from industry?		16%	16%
6. Typically how many seminars or other presentations (exclusive of the thesis defense) does a student give during the Ph.D. career to audiences other than the student's own research group?		2.8	2.6
7. Do you require your graduate students to create and defend original research proposal(s)?	Yes	84%	84%
	No	16%	16%
8. What percentage of your graduate students get some experience as teachers?		93%	91%
What percentage teach discussion sections?		40%	48%
Do you give them some formal instruction in teaching before they start?	Yes	86%	91%
	No	14%	9%
9. What percentage of your graduate students participate in interdisciplinary programs involving other departments?		17%	14%
10. What is included in your Ph.D. examination system?			
Cumulative examinations		73%	70%
Oral preliminary exam		53%	61%
Comprehensive written exam		33%	29%
Comprehensive oral exam		44%	46%
Research proposal(s)		86%	85%
Thesis defense		97%	94%
11. What percentage of your students select a research advisor within			
2 Months		20%	19%
6 Months		72%	75%
Later		33%	27%

Table 1. Results of Survey of Ph.D. Programs in Chemistry *continued*

Question		Average[b] Unweighted	Weighted
Do advisors speak about their research to the entering students as a group?	Yes	68%	77%
	No	32%	23%
Do you require or permit laboratory rotations before a final advisor is chosen?	Yes	26%	26%
	No	74%	74%
12. Do you have a language requirement for the Ph.D.?	Yes	19%	15%
	No	81%	85%
13. Do you have a limit on the amount of time allowed for achieving a Ph.D.?	Yes	68%	63%
	No	32%	37%
If yes, how many years?		7.2 yr	7.2 yr
Do you have a limit on years of support (of any kind)?	Yes	71%	70%
	No	29%	30%
If yes, how many years?		5.5 yr	5.6 yr
What is the mean time to degree? (years)		5.1 yr	5.5 yr
14. Does each graduate student have an advisory committee that follows his/her progress through graduate study and whose members serve on the final Ph.D. committee?	Yes	89%	86%
	No	11%	14%
15. Does each graduate student give a public final oral presentation of the thesis?	Yes	92%	89%
	No	8%	11%
16. What approximate percentage of your total graduate student support is by[d]			
Teaching assistantships		50%	44%
Faculty-generated research funds		38%	43%
University or department fellowships		7%	6%
Government fellowships		4%	4%
Training grants, interdisciplinary		2%	3%
Training grants, chemistry		2%	3%
Other		6%	4%
Of the total support of graduate students, what percentage comes from industry?		7%	7%

[a] Based on 162 responses received by January 1, 1997. Not all respondents answered each question.
[b] Unweighted average: sum of responses divided by the number of institutions responding to that question.
Weighted average: sum of responses, each multiplied by the number of students in the program, divided by the total number of students in all programs responding to that question.
[c] Equal by definition to the unweighted average.
[d] Responses were approximate, explaining why percentages in question 16 do not sum to 100%.

*The Master's Degree in Chemistry**

CPT is charged with examining education in chemistry at the postsecondary level. The ACS approval program for undergraduate departments of chemistry and the certification of bachelor's degree graduates is well known. In graduate education, the committee's most visible activity is the biennial production of the *ACS Directory of Graduate Research*. In addition, CPT has studied many facets of graduate training in chemistry and periodically has published reports of these studies. In the last few years, there has been an intense national debate about the Ph.D. training of scientists (1–3). CPT recently completed a survey of current practices in Ph.D. training, and reported the results in this *Newsletter*. Yet in focusing on the Ph.D., much of this recent attention has ignored a significant component of postgraduate training in chemistry in the U.S.: the master's degree.

Career opportunities in chemistry appear to be changing, particularly in industry and other non-academic positions. It is an often repeated statement that today's graduates must anticipate not one but several careers in their lifetimes. Employers seek graduates at all levels with stronger communication skills, more work experience, broader knowledge and greater flexibility than ever before, but look for this in addition to very sound and broad training in the chemical sciences. It is increasingly challenging to cover the expanding field of chemistry in a four-year program. Obtaining a Master's degree offers one attractive solution.

There are obvious indicators that the Master's degree in chemistry is alive and well. The numbers of Master's degrees awarded in chemistry are quite comparable to those for the Ph.D, and have showed an upturn in this decade (Table 2). The annual salary survey conducted by the ACS shows a consistent and significant added value of the M.S. degree for professional chemists as they enter the workforce (Table 3). Nevertheless, it sometimes appears that chemistry master's programs lack visibility.

CPT recently conducted two brief surveys about the Master's program in chemistry. This report summarizes our findings. Both surveys were sent to department chairs of chemistry graduate programs. Survey I was mailed to 318 schools; of the 250 responses, 158 were from Ph.D. granting-institutions, and 92 were from institutions whose highest degree is the Master's.

Survey I questions are listed on p. 7, and the results summarized in Table 2. This survey was designed to learn about the structure of Master's programs. Survey II, which followed, was designed to learn more about educational goals. Survey II questions are listed on p.7, with results summarized in Table 3. This follow-up survey was sent to chairs of all M.S.-only and to 66 of the Ph.D.-granting departments which had returned the first survey. The latter were included in Survey II if they had awarded at least five Master's degrees in the most recent year, and if the number of Ph.D.s awarded did not exceed 50% more than the number of Master's. Our objective was to hear from the Ph.D. schools with more active Master's programs.

Master's programs in the U.S. differ widely in size. Many Ph.D. schools award more Master's degrees than the number of students they admit specifically for Master's programs. These frequently represent degrees awarded to students whose original objective was the Ph.D. Some are earned as a milepost, awarded to a student who is continuing to work toward the Ph.D. at the same school. The number of such degrees is difficult to ascertain. A quick review of any CPT Annual Report shows that many schools routinely award many more Ph.D.s than Master's, suggesting that many of their doctoral students do not first obtain an M.S. degree. The opportunity may not be offered; it also might require extra effort. At other places, depending on local customs and incentives, all Ph.D. candidates are awarded Master's degrees. A second category of Master's has been called a consolation prize: a degree awarded to students who entered a program planning to obtain a Ph.D., but left before completing that degree. But these are only part of the picture. In Survey II, 63% of Ph.D. schools admit students specifically for Master's degree programs. A rough estimate, based on our overall data, is that more than three quarters of the Master's degrees awarded in chemistry in the U.S. go to students who entered graduate school seeking that degree.

Master's degree programs in American universities vary widely in some respects but are quite similar in others. The mean values of both the reported minimum time toward the degree (1.7 years) and the average time (2.5 years) are the same at Master's and doctoral universities. The average course credit hour requirement, (about 29), roughly equivalent to a year of coursework, is quite common. Some schools require two years of coursework, and a few have no firm course requirement. Master's-only schools report a slightly higher proportion of students whose bachelor's degrees were earned outside the U.S. (39% as opposed to 33%). They also enroll a considerably higher proportion of students who are part-time (33% as opposed to 17%). However, even at M.S.-only schools, full-time study is the norm.

Requirements for the Master's degrees vary. It is not uncommon to have multiple tracks. Frequently, schools offer both a coursework-only Master's, and a research-based Master's. Coursework-only Master's degrees are

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offered at 25% of the Master's-level schools, and at 42% of the Ph.D. schools. Specific courses for Master's students and specific exams for Master's students are prevalent, but far from universal. A small percentage of the respondents to Survey I answered affirmatively that their program was "specifically designed for employment with that degree only".

Brochures and other materials submitted with Survey I suggest a wide range of educational goals for Master's programs in Chemistry. The second survey was designed to obtain a clearer picture of that breadth. Although the response rate was good, the data remain a bit difficult to interpret. Like Ph.D. programs, most Master's programs are designed broadly to accomplish a variety of goals: preparing students for jobs in industry, in education, and to go on to further study. In some cases, there are separate tracks, with separate degree requirements, but that is not common. About one-third of Master's programs report teacher-training as one of their goals. This number is about the same at Master's and Ph.D. schools. Special programs for in-service teachers seem to be more prevalent at non-Ph.D. schools. One interesting example is at Bucknell University, where high school teachers can earn a Master's degree in chemistry after three summers at Bucknell.

Preparation for work in industry is a common objective for Master's programs: 59% of Ph.D. schools and 89% of Master's schools reported this goal. But the number of programs with a specific industrial focus is small. About 4% of respondents described their program as preparing for a particular sector of industry, and 6% reported industry partnerships. While the numbers are small, Master's programs with a particular industrial emphasis or with specific connections to industry can be attractive to both students and to industry. Examples include a program in Coatings Technology and Polymer Chemistry at DePaul University, a program in Industrial Chemistry at the University of Central Florida, the Lehigh Educational Satellite Network, which allows Lehigh courses to be offered to employees at multiple corporate sites, and the University of Colorado Denver's program with an Environmental and Biotech-Pharmaceutical emphasis. Several schools offer combined B.S./M.S. degrees, including Idaho State and Vassar.

Today, one hears calls for the revitalization of the Master's degree, or at the least, an enhancement of its prestige. Prestige is a subjective matter, but visibility is less so, and often the former accompanies the latter. How can the ACS contribute to bringing better visibility to Master's programs? An ACS publication, the *ACS Directory of Graduate Research*, is always useful to students thinking about graduate study. The most prestigious Ph.D. programs are highly visible, but how does a student find a Master's program, perhaps one with a particular emphasis? Posters and brochures are ephemeral, and are easily buried in the next day's mail. Today's technology suggests an attractive and cost-effective answer. A chemistry graduate study web page, accessible from the ACS ChemCenter, could list programs at various levels, including special emphases, with hypertext links to the schools. CPT is exploring this possibility and welcomes your advice and suggestions.

References

1. "Graduate Training and Postdoctoral Training in the Mathematical and Physical Sciences", NSF Directorate for Mathematical and Physical Sciences, Workshop Report, 1995.
2. "Reshaping the Graduate Education of Scientists and Engineers" National Academy of Sciences Committee on Science, Engineering, and Public Policy. 1995.
3. "Patterns of Recent Doctorates in Chemistry: Institutional Perspective and Imperatives for Change", ACS, 1995. [The Lavallee Report]

Table 2

CPT Survey I Results	All	Master's Schools					Doctoral Schools				
Question		**Replies**	**Mean**	**Min**	**Max**	**Total**	**Replies**	**Mean**	**Min**	**Max**	**Total**
Surveys returned	250	92					158				
Q3a. MS students admitted	1257	90	6.8	1	30	611	155	4.2	0	90	646
Q3b. MS degrees	1195	91	5.0	1	25	452	150	5.0	0	20	743
Q4a. Minimum time	1.7	89	1.7	0	3		153	1.7	0	5	
Q4b. Typical time	2.5	91	2.5	1.3	4		156	2.5	0	5	
Q5. Semester hours	28.6	85	30.3	7	45		154	27.7	0	66	
Q6. % domestic BA	65	86	60.5	5	100		106	67.3	10	100	
Q7. % part time etc.	23	92	33.3	0	100		81	16.7	0	100	
Degree requirements	**%Y**	**#**	**%Y**	**Y**	**N**		**#**	**%Y**	**Y**	**N**	
Q8. Thesis	74	89	82	73	16		146	70	102	44	
Q9. If not, research	59	34	59	20	14		80	59	47	33	
Q10. Coursework only	35	92	25	23	69		151	42	63	88	
Q11a. Specific courses	65	91	85	77	14		155	54	83	72	
Q11b. If so, taken by others	34	61	70	43	18		106	13	14	92	
Q12a. Specific exams	52	91	66	60	31		154	44	68	86	
Q12b. If so: different	52	53	79	42	11		155	35	28	53	
Q13. For jobs at MS level	16	89	19	17	72		146	14	21	130	

Table 3

CPT Survey II Results	Total	Masters		Doctoral	
Surveys # received	130		74		56
# sent	158		92		66
Survey response	82%	80%		85%	
Admit for MA/MS?				63%	35
Goals	**%Y**	**%Y**	**Y**	**%Y**	**Y**
Q1. Industry	76.2	89	66	59	33
a. partnership	6.2	3	2	11	6
b. sector	3.8	5	4	2	1
c. general	63.8	82	61	39	22
Q2. Teacher training	30.8	32	24	29	16
a. in-service	11.5	16	12	5	3
b. preservice	8.5	9	7	7	4
c. both	19.2	20	15	18	10
Q3. Further study	73.1	91	67	50	28
Q4. General	50.0	65	48	30	17
Q5. BS/MS Combined	17.7	19	14	16	9
Q6. Other	6.2	5	4	7	4

Survey I

[The order of the questions has been changed.]

1. What Master's degree(s) does your department offer?
2. Does your department also offer a Ph.D.?
3a. How many students are admitted annually specifically for study in the Master's program?
b. How many Master's degrees are awarded annually as a final degree?
4a. What is the minimum time required to earn a Master's degree (years)?
b. What is the typical time required?
5. What number of semester hours is required?
6. What is the Bachelor's origin of your Master's students?
Domestic ____________% Foreign ________%
7. What percentage of your Master's degree students fall in the overall category of part-time/continuing education/employer-supported?
8. Is a thesis required for the Master's degree?
9. If not, is research required?
10. Can a Master's degree be earned solely on the basis of courses taken?
11a. Are there specific courses required for the Master's degree students?
b. If so, do they differ from those taken by other degree candidates?
12a. Are there specific exams required for Master's degree students?
b. If so, do they differ from those taken by other degree candidates?
13. Is your Master's degree program specifically designed to prepare students for employment with that degree only? If so, please elaborate.
14. The CPT is interested in innovative or nontraditional Master's degree programs and welcomes your submission of degree descriptions and other literature.

Survey II

[Asked of Ph.D. schools only]

Do you regularly admit students whose stated objective is obtaining a Master's degree, not a Ph.D. degree?
Yes [ ] No [ ]

If the answer is yes, please complete the following:

[Asked of all surveyed]

Which of the following best describes your goals for your Master's program(s)?
(You may check more than one answer):

1. Preparation for industry — Yes [ ] No [ ]
If so, is it:
a. a partnership with a specific employer — a. [ ]
b. focused on a particular sector (e.g., polymers): ____________________ — b. [ ]
c. general — c. [ ]

2. Teacher training — Yes [ ] No [ ]
If so, is it:
a. for in-service teachers — a. [ ]
b. for preservice teachers — b. [ ]
c. general — c. [ ]

3. Preparation for more advanced study — Yes [ ] No [ ]
4. General — Yes [ ] No [ ]
5. Combined BS/MS program — Yes [ ] No [ ]
6. Other: ________________________ — Yes [ ] No [ ]

*Survey of Ph.D. Recipients in Chemistry**
Part 1. Statistical Analysis

Recently CPT has again become involved in studies of graduate education in chemistry in the United States. In 1996 a survey of Ph.D. chemistry programs was conducted with the aim of determining what the present practices were among the 190 Ph.D. programs in chemistry known to CPT. The results of this survey were published in a Special Report in the *CPT Newsletter* (Vol. II, No. 2, Spring 1997). A separate survey of master's degree programs was also conducted and the responses were described in a second Special Report (*CPT Newsletter*, Vol. II, No. 3, Spring 1998). These two surveys provided extremely interesting new information about the nature of graduate education in chemistry as it exists late in the twentieth century.

To gain even more insight into the question, CPT decided to seek the opinions and advice of those who have been students in U.S. graduate programs. We chose to limit the survey to recipients of the Ph.D. degree and, because we wanted to detect any differences in attitudes and opinions between those who received the Ph.D. at different times, the questionnaires were mailed to two cohorts of equal size. These two groups were those 33–37 years of age in 1998 and those 43–47 years.

In mid-1998 the questionnaire was sent to 4000 randomly selected ACS members who have Ph.D. degrees. An equal number (2000) of members surveyed were in each cohort. The response was very gratifying and, after one follow-up mailing to those who had not yet responded, it was found that 2381 individuals (59.5%) had responded. Of these, 2336 individuals reported receiving the Ph.D. from a graduate institution in the United States, and it was their responses that were analyzed. The selection of the two groups according to age was necessitated by the fact that ACS does not have information about the year that members received the degree. It was this latter figure that was desired for selecting the two groups. Interestingly, the procedure resulted in the average year of receipt of the Ph.D. differing by almost exactly ten years between the two groups, 1990.8 for those in their thirties and 1981.3 for those in their forties.

Comments about response rate. The response rate of about 60% indicates strong interest in the survey by those who were polled. Even more encouraging was the fact that about one thousand respondents provided written comments concerning their experience in graduate education. An analysis of those written comments will be the subject of Part 2 of this Special Report.

In spite of the fact that six out of ten of those surveyed returned questionnaires to CPT, it is important to bear in mind that 40% did not respond and there is no way of knowing how their views would affect the average responses to be reported here. Nevertheless, it is believed that the numerical results that were obtained will be of significant interest in spite of the above reservation that the average results might not be representative of the whole group.

Questions included in the survey and the average responses. The questions in the survey are presented in Table 4 along with the average of the responses on each question, the standard deviation and (where relevant) the percentage of those responding "does not apply". Most but not all of the questions were constructed in such a way that a low numerical response (the range was 1 to 5) indicated a generally favorable impression of the particular aspect of graduate education embodied in the question. Thus a quick scan of the responses in Table 4 reveals many average responses in the range of 1.6 to 2.5, which gives the general impression that the Ph.D. recipients were favorably disposed toward their program of study.

Question 2 reveals that on the average the respondents felt that the courses taken in the program were appropriate and useful (mean response: 2.27). More courses outside chemistry were regarded as important (question 4, 2.13), but the respondents were more or less neutral when asked if more courses in chemistry would have been useful (question 3, 2.77). Seminars and colloquia (question 5, 2.04), formal presentations (question 6, 1.69), and original research proposals (question 7, 1.69) were features that were valued. Those for whom an original research proposal was not required (79%) were less certain of its value (question 8, 2.31) than those who faced such a requirement. Experience as a teaching assistant was regarded as quite valuable (question 9, 1.92).

Question 10 attempts to elicit the respondents' attitudes about interdisciplinary study. Respondents were asked to respond to the single question (10a, 10b, or 10c) most descriptive of the interdisciplinary nature of the Ph.D. research. Those who had taken part in a formal interdisciplinary program with participation by scientists outside chemistry were quite pleased with the result (question 10a, 1.70), and those whose interdisciplinary research did not involve such interactions with scientists outside chemistry generally felt that such interactions would have been useful (question 10b, 2.00). Those whose research was in one of the traditionally defined areas of chemistry were less pleased with this aspect of the Ph.D. program (question 10c, 2.58).

The respondents favorably recalled cumulative examinations (question 11, 2.69), oral examinations (question 12, 2.17) and comprehensive written examinations (question 13, 2.55). However, when asked if facility in a foreign language was important in their present position, the response was clearly on the nega-

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Table 4. Responses to Survey of Ph.D. Recipients[a]

	Mean	Standard Deviation	%"does not apply"
1. Was your Ph.D. institution U.S. or non-U.S.?		**2% non-U.S.[b]**	
Questions 2 through 16 asked for a response from 1 (strongly agree) to 5 (strongly disagree) or "does not apply".			
2. The formal courses that I took in my Ph.D. program adequately prepared me for my present position.	2.27	0.97	2%
3. I would have benefited from additional courses in chemistry.	2.77	1.08	1%
4. I would have benefited from additional courses in disciplines other than chemistry.	2.13	0.98	1%
5. The seminars and colloquia that I attended during my Ph.D. studies contributed significantly to my education.	2.04	0.95	<1%
6. The formal presentations (exclusive of research group presentations and teaching) that I made during my graduate experience contributed significantly to my education.	1.69	0.80	3%
7. I was required to create and present/submit an original research proposal(s) and believe that this experience contributed significantly to my graduate education.	1.69	0.83	15%
8. An original research proposal(s) was not required, and I believe that I would have benefited from such an experience.	2.31	1.07	79%
9. My experience as a teaching assistant (or other teaching activities) has helped me in the performance of my job.	1.92	0.91	3%
10. Please respond to the ONE question (a,b, or c) that best describes your experience with the interdisciplinary aspects of your graduate education.			
a. My graduate research involved a formal interdisciplinary program that included scientists from areas outside chemistry. This experience has proven to be beneficial to me in my professional career.	1.70	0.99	36%
b. My graduate research was interdisciplinary in nature but did not include formal interactions with scientists outside chemistry. I would have benefited from such interactions.	2.00	0.79	33%
c. My graduate research was focused within the traditionally defined boundaries of chemistry. This experience has adequately prepared me for my present position.	2.58	1.03	11%
11. The cumulative examinations that I took contributed significantly to my graduate education.	2.69	1.14	18%
12. The oral examination that I took prior to my thesis defense was beneficial.	2.17	0.93	13%
13. The comprehensive written examination was an important component of my graduate education.	2.55	1.02	58%
14. Facility in a foreign language is important in my position.	3.56	1.15	8%
15. The foreign language requirement in my Ph.D. program gave me a significant advantage in my professional career.	3.88	0.98	32%
16. The faculty advisory committee that monitored my progress toward the Ph.D. was constructive and helpful.	2.90	1.11	7%
Questions 17 through 21 asked for a response from 1(excellent) to 5 (poor).			
17. Please rate the contributions of your research advisor to your graduate education in the following areas: a. Mentoring (e.g. role modeling, enthusiasm, work ethic, etc.)	1.95	1.13	
b. Career advisement	2.95	1.25	
c. Establishing appropriate standards (scientific, ethical)	1.76	0.97	
d. Establishing appropriate requirements (e.g. research reports, meeting deadlines, planning, etc.)	2.35	1.11	
e. Increasing your scientific knowledge (relevant, up-to-date)	1.86	0.94	
f. How would you rate the overall effectiveness of your graduate research advisor?	2.06	1.03	

	Mean	Standard Deviation	%"does not apply"
18. How would you rate the quality and quantity of the instrumentation facilities available to you during your graduate experience?	1.88	0.95	
19. How would you rate the quality and quantity of the library holdings at your graduate institution?	1.57	0.74	
20. How would you rate the quality and quantity of the chemistry physical plant (i.e. buildings and laboratories) at your graduate institution?	2.11	0.97	
21. How would you characterize the level of financial support (TA or RA stipend, fellowship, etc.) that you received as a graduate student?	2.23	1.06	
Questions 22 through 26 asked for a response from 1 (strongly agree) to 5 (strongly disagree) or "does not apply".			
22. Students in my graduate program participated in institutional governance (committee membership, etc.)	3.72	1.02	12%
23. Students in my graduate program were encouraged to develop computer skills.	2.66	1.12	4%
24. I was encouraged to atttend and participate in professional meetings.	2.35	1.10	<1%
25. In graduate school, I developed a network of friends and associates that has benefited me significantly in my professional career.	2.80	1.14	<1%
26. The importance of teamwork was emphasized in my graduate program.	3.20	1.08	<1%

[a] Possible responses for questions 2-16 and 22-26 were: strongly agree(1), agree(2), neutral(3), disagree(4), strongly disagree (5) and "does not apply". For questions 17-21, a total of five choices was available ranging from 1 (excellent) to 5 (poor).

[b] Though those holding Ph.D. degrees from non-U.S. institutions were asked to return the survey form without responding to questions 2-26, it is thought that many did not do so and simply discarded the form. Thus 2% non-U.S. Ph.D. degrees is probably a lower limit for the group of ACS members that was surveyed.

tive side (question 14, 3.56), and the foreign language requirement was even less valuable (question 15, 3.88). It should be noted that only 32% indicated "does not apply" in question 15, which suggests that the removal of foreign language requirements from Ph.D. programs is a recent development that was not in place when the respondents were in school. (81% reported no foreign language requirement in 1996. See "Survey of Ph.D. Programs in Chemistry," *CPT Special Report*, Spring 1997.) The response concerning the value of the faculty advisory committee was close to neutral (question 16, 2.90).

Question 17 was designed to assess the performance of the research advisor, and the response was generally favorable (question 17f, 2.06) with strongest responses concerning mentoring (question 17a, 1.95), establishing appropriate standards (question 17c, 1.76), and imparting scientific knowledge (question 17e, 1.86). In the effectiveness of the research advisor in career advisement the response was almost neutral (question 17b, 2.95).

The remaining questions sought the respondents' impressions of the graduate institution and certain practices in the department. Instrumentation (question 18, 1.88), library (question 19, 1.57), physical plant (question 20, 2.11), and financial support (question 21, 2.23) were given good to very good marks. Few students participated in institutional governance (question 22, 3.72), but there was some encouragement to develop computer skills (question 23, 2.66) and participate in professional meetings (question 24, 2.35). The respondents reported that networking (question 25, 2.80) was not stressed, and that teamwork was not strongly emphasized (question 26, 3.20), the latter result perhaps reflecting the traditional practice of giving each Ph.D. student his or her own research project with little effort toward promoting teamwork.

Standard deviations. The standard deviations reported in Table 4 provide some idea of the range of responses for each question. The magnitude of the standard deviations falls between about 0.7 and 1.2. This statistical parameter provides a reminder that an average response of 2.00 (as in question 10b), for example, does not indicate a uniform response of "agree" (assigned a value of 2) from the respondents but rather a range of responses characterized by the standard deviation of 0.79. Table 5 provides a tabular view of the distribution for 10b and three other questions including one with a very low average response (question 6), a neutral response (question 17b), and a high average response (question 15). Thus, when considering the average responses discussed above, it is important to remember that the respondents actually held a wide range of opinions about each question.

Differences between responses given by different groups of respondents: "thirties group" and "forties group". In examining the average responses from the two groups it was striking to see how similar they were. First of all, almost identical response rates were obtained for the "thirties group" (62%) and "forties

Table 5. Examples of Distribution of Responses

		Percent Responding				
Question	Average Response	Strongly Agree (1)	Agree (2)	Neutral (3)	Disagree (4)	Strongly Disagree (5)
10b	2.00	23.5	59.7	11.1	4.6	1.0
6	1.69	47.8	40.2	7.8	3.6	0.5
17b	2.95	12.8	27.3	26.8	18.3	14.8
15	3.88	1.7	8.4	18.7	42.2	28.9

group" (58%). To determine if the differences in the mean responses for the two groups were statistically significant, the t-test was applied. This statistical parameter allows one to say whether the two means are statistically different with a certain degree of probability. Using a 95% confidence level, it was found that responses of the two groups were significantly different for only 13 of the 33 questions and subquestions that were asked. These 13 were questions 3, 5, 6, 11, 14, 15, 16, 17d, 18, 22, 23, 24 and 25. In this analysis, a computed t-value greater than 1.96 indicates a statistically significant difference in the two means. One of the largest t-values was for question 3 (t = 6.0) where members of the "thirties group" were more likely to report that they would have benefited from more courses in chemistry. It is worth asking if this is a reflection of the rumored reduction of courses requirements over the last two decades in our Ph.D. programs.

Another significant difference was found for question 6 (t = 3.3) where the "forties group" was more likely to value the role of formal presentations in the graduate program. On question 15, the "forties group" was more likely (t = 3.6) to report that the foreign language requirement was valuable. The "thirties group" had a stronger impression of the instrumentation available to them in their graduate work (question 18; t = 6.7). With respect to participation in institutional governance (question 22; t = 4.3), development of computer skills (question 23; t = 6.1), and networking (question 25; t = 5.5), the "forties group" reported significantly less involvement. The "thirties group" was more likely to report that they were encouraged to attend and participate in professional meetings (question 24; t = 2.4).

Differences between responses given by different groups of respondents: women and men. It was found that 24.0% of the total respondents were women. Again the average responses of the two groups (men and women) were very similar, with 12 of 33 questions showing a statistically significant (95% confidence) difference between the two means. Here, only three questions showed t-values above 3. They were question 2 (t = 3.1), where men were more pleased with the formal courses they took; question 5 (t = 4.6), where men were more likely to report satisfaction with seminars and colloquia; and question 11 (t = 3.2), where men were again more favorably impressed by the cumulative examinations than were the women. Mentoring by the research advisor was evaluated less favorably by women than men (question 17a) with a t-value of 2.6.

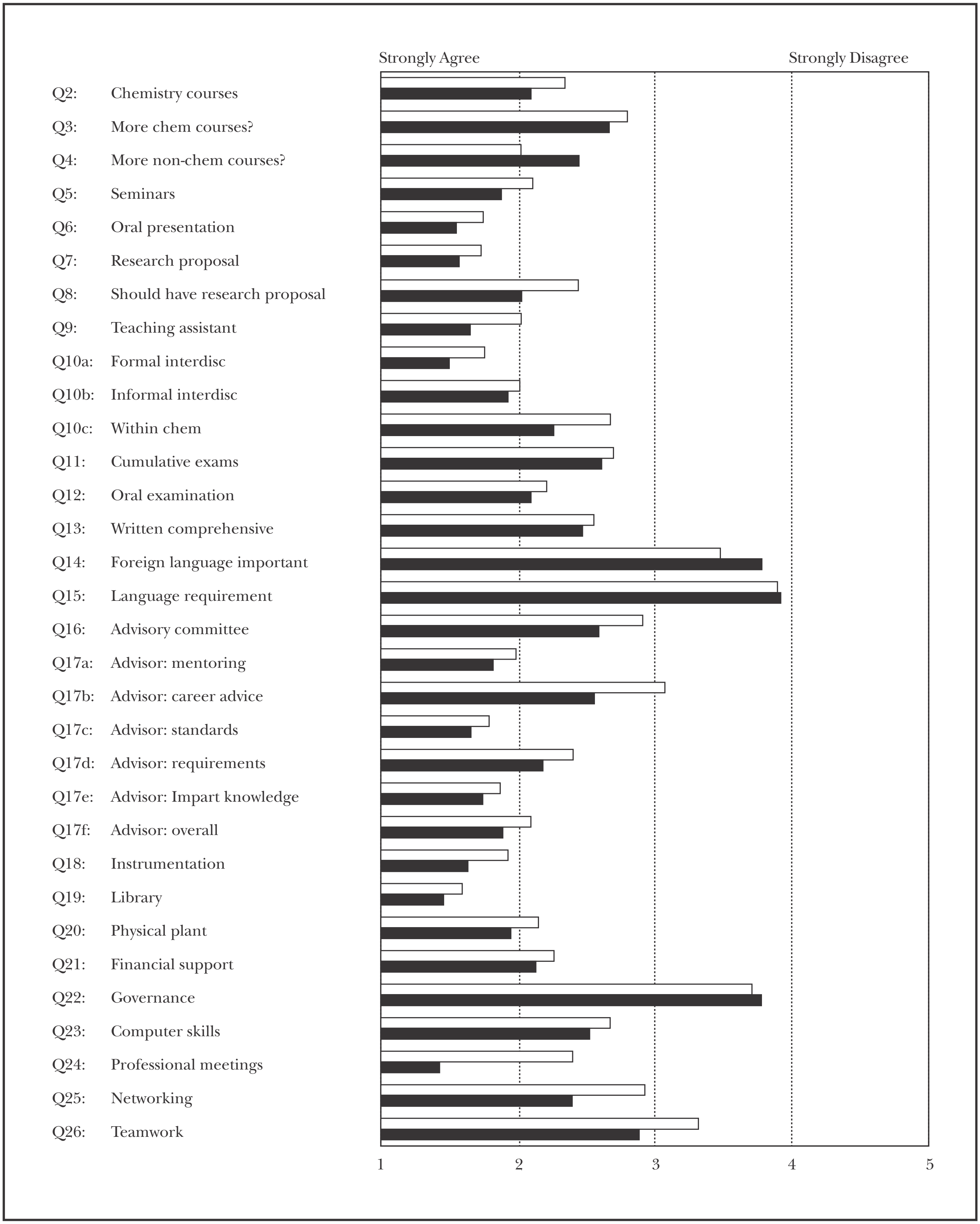
Differences between responses given by different groups of respondents: those employed in industry compared to those in academia. Among the groups compared, the differences between those Ph.D. recipients who are employed in industry (65%) versus those in academia (23%) were definitely the most pronounced (Figure 2). In this case, statistically significant differences in mean response were found for 27 of the 33 questions and subquestions. The questions that evoked statistically identical responses from the two groups were 10b, 11, 13, 15, 16, and 22. A brief scan of Figure 1 reveals that the industrial group had a less favorable opinion of their graduate education than the academic cohort on almost every question asked. Taken at face value, these results support the frequently expressed view that our Ph.D. programs are not preparing individuals for employment in industry as effectively as they should.

Some particularly significant differences will be highlighted. Compared to their academic colleagues, industrial chemists were less happy with the formal courses that they took (question 2; t = 5.1), and they were more likely to report that more courses outside chemistry would be beneficial (question 4; t = 8.3). Industrial chemists were less impressed by seminars and colloquia (question 5; t = 4.4) and by the formal presentations required in the program (question 6; t = 4.6). Those in industry found that experience as a teaching assistant was less valuable to them than did the academic group (question 9; t = 8.3), and for those whose research was in one of the traditionally defined fields of chemistry (question 10c; t = 6.0), industrial chemists were the less satisfied group.

Interestingly, those in industry were more likely to report that facility in a foreign language was important in their present job (question 14; t = 4.9), and the industrial group was less impressed with the career advisement they received from the research advisor (question 17b; t = 8.1). This latter result probably arises in large part from the lack of experience in industry that is characteristic of most professors. Ph.D. recipients employed in academia were more favorably impressed with the instrumentation available to them than were their industrial counterparts (question 18; t = 5.9), and the academic group was more likely to report that networking (question 25; t = 9.4) and teamwork (question 26; t = 7.5) were stressed in the graduate program.

Other characteristics of the respondents. Respondents were requested to provide additional information

Figure 2. Mean responses of Ph.D. chemists employed in industry (open bars) compared to those in academia (filled bars)



about themselves. Some of this data is of interest to the question of Ph.D. programs in chemistry because it reflects trends that are underway in our discipline.

As stated earlier, 24% of the total respondents were women. When the "thirties group" and "forties group" were compared, it was found that only 16.8% of the forties group (average completion year 1981) were women, whereas the percentage had increased to 30.9% by the time the thirties group had completed the degree (average completion year 1991). This reflects the well-known increase over the last few decades in the number of women earning the Ph.D. in chemistry.

Sixty-eight percent of the respondents completed their Ph.D. program in a public institution, while the remainder received the Ph.D. from a private institution. By contrast, only 52% of the respondents attended a public institution as undergraduates while 48% attended private schools.

The average time required to complete the Ph.D. was 5.06 years for all respondents. For the various groups, the average was 5.08 years for the "thirties group", 5.04 years for the "forties group", 5.12 years for women, 5.04 for men, 5.00 years for those in industry, and 5.11 years for those in academia.

Some students required significantly longer than average to complete the degree. Of those responding, 10.0% reported spending more than six years in graduate school (3.4% required more than seven years). When groups were compared, it was found that 8.09% of the "thirties group" spent more than six years (2.2% more than seven years), while 12.0% of the "forties group" required more than six years (4.7% more than seven years). For women, 9.8% required more than six years to complete the Ph.D. (3.1% more than seven years), and for men the percentages were 10.0% (more than six years) and 3.4% (more than seven years).

In terms of present employment, 65% reported industrial employment, 23% were in academic positions, 6% in government, 2.8% "other", 1.4% self-employed, and 1.3% unemployed.

The respondents were asked to report the field in which they did graduate work and the specialty most closely related to their present employment. A summary of the results is given in Table 6.

The data in Table 4 indicate that the vast majority (88%) of Ph.D. degrees held by the respondents were in the traditional subdivisions of chemistry: organic, inorganic, physical, analytical, and biochemistry. When the fields most relevant to present employment are examined, it can be seen that some migration has occurred between receipt of the Ph.D. and employment in the years that have followed. Compared to the percentages receiving degrees in a given field, significant increases are seen in the fraction of Ph.D. chemists reporting the field most relevant to their employment to be analytical chemistry, biochemistry, polymer chemistry, and materials science, to name a few. These results emphasize the importance of a broadly based education for Ph.D. chemists so that they will be able to move into different areas as opportunities present themselves. Accomplishing this, while providing rigorous training in the area of specialization, is of course a difficult task.

Table 6. Distribution of Ph.D. Degrees and Present Employment by Field

Field of Specialization	Percent Reporting Ph.D. in the Field	Percent Reporting Present Employment Most Closely Related to the Field
Organic Chemistry	36.3	24.7
Inorganic Chemistry	19.3	5.8
Physical Chemistry	14.4	6.6
Analytical Chemistry	12.4	16.6
Biochemistry	5.2	7.6
Other Chemical Science	3.2	3.5
Polymer Chemistry	2.9	8.6
Chemical Engineering	2.5	3.3
General Chemistry	1.3	3.8
Materials Science	0.9	4.9
Environmental Chemistry	0.6	2.4
Agricultural/Food Chemistry	0.4	1.6
Other Non-Chemistry	0.3	4.6
Computer Science	0.2	1.6
Business Administration	0.1	2.3
Clinical Chemistry	0.1	0.6
Law	0.0	1.6

Summary. A survey has been conducted of Ph.D. recipients from U.S. universities who are members of ACS. Two groups were surveyed. The first was a randomly selected group of 2000 chemists 33–37 years of age in 1998, and the second included 2000 Ph.D. recipients 43–47 years old. The results indicate a generally favorable view of the Ph.D. degree programs undertaken by the respondents. However, there were some areas of dissatisfaction noted. About 1000 respondents provided specific written comments, both critical and adulatory. An analysis of those comments will be provided in Part 2 of this Special Report.

Significant differences between the mean responses of the "thirties group" and the "forties group" were found on 13 of 33 questions, while differences between the responses of men and women were statistically significant in 12 cases. The most striking differences were found when comparison was made between Ph.D. chemists employed in industry and those in academia. Here, statistically significant differences were found on 27 questions, and on the average, the industrial group expressed a distinctly lower opinion of their graduate experience than did those in academia. It is recommended that serious consideration be given to these differences by graduate programs seeking to enhance the preparation of their Ph.D. graduates for careers in industry.

*Survey of Ph.D. Recipients in Chemistry**
Part 2. Analysis of Written Comments

The more things change…

"*The length of time required for the Ph.D. should certainly not be less than three years.*"
Comment of department chairman, 1947

"*The exploitation of graduate students in the U.S. is a disgrace. As a reward, after working for five or six years to earn the Ph.D., they are told they are not qualified for work unless they do a postdoc. If after all this work, Ph.D. chemists are not employable without a postdoctoral appointment, the system is broken and must be fixed.*"
Comment by unemployed Ph.D., 1998

…the more they stay the same.

"*I would strongly advise that every graduate department give a good course in industrial chemistry, including field trips and some attention to such matters as patents, activities of chemists in industry, etc., and supplement it with talks on technical subjects and by men in industry.*"
Comment by Ph.D. working in industry, 1947

"*My chemistry department prepared graduates for academics more than industry … [the institution of] concrete steps, such as graduate internships, may be a better approach than professors imagining what industry is like from the hallowed halls of academe. My experience as a retail sales clerk was in some ways a better background for what I do now than some of the chemistry courses I took.*"
Comment by Ph.D. working in industry, 1998

CPT has long been concerned with the health of graduate education in chemistry in the United States. Starting in 1947, CPT published a series of reports[1] that provided information about the requirements, structure, size, and capacity of the Ph.D. programs in chemistry as well as the opinions of graduates of those programs. After a hiatus of about two decades, CPT returned to this area of concern in 1996 with a survey of Ph.D.-granting institutions and in 1998 with a survey of recipients of the Ph.D. degree in chemistry.

The quotations above include two taken from the first report (1947) as well as two comments from the most recent survey. The landscape of Ph.D. education has changed dramatically over the last half century. In 1947, 78 departments were found to offer the Ph.D. degree in chemistry, but by 1996 that number had increased to about 190. Judging by the first quotation, there was apparently concern in 1947 that some schools were graduating students with less than three years of postbaccalaureate education. In contrast, departments in the 1996 survey and Ph.D. recipients in the 1998 survey reported that the average time to degree had increased to more than five years, with some students requiring significantly longer periods of study.

However, some themes have remained more or less constant, though the emphasis may have changed. The third quotation indicates that in 1947 it was already recognized that the Ph.D. programs could do a better job of preparing the graduate for a career in industry. As shown by the final quotation, that concern remains to this day and is perhaps even more prevalent than it has been in the past.

Background of the present survey. Those surveyed were 4000 randomly selected ACS members who hold the Ph.D. degree. There were two groups, one composed of individuals who were 33–37 years of age in 1998 and the other comprising those who were 43–47 years. The average year of completion of the Ph.D. was 1991 for the first group and 1981 for the second. A total of 2381 individuals returned the questionnaires with responses to 26 questions concerning their experience in graduate school. A statistical analysis of those responses along with a commentary was the basis of Part 1 of this report.[2]

Written comments were also solicited. Specifically, the questionnaire included the following invitation:

"*Please elaborate on what you perceive to be the strengths and weaknesses of the graduate program from which you received your Ph.D. We are very interested in your opinions about how current practices could be improved to provide today's graduate students with a better, more relevant graduate experience.*"

CPT was gratified to find that 978 (41%) of those responding provided written comments ranging from a sentence or two to extensive multipage essays with detailed proposals for the reform of graduate education. These written comments are the raw material for this second part of the report on the survey of Ph.D. recipients.

Procedures used in the analysis. Initially, 150 questionnaires were selected for study (evenly divided between the two age groups), and the comments were categorized by subject, resulting in approximately 30 different categories. From these categories, the 11 most frequently mentioned were chosen. Each of these categories was mentioned by more than 6% of the initial group of respondents. In this way, the most important categories were identified.

**Initially reported Fall 2000*

The analysis was then extended to all 978 reports, and the comments in each category were further described by their nature:

"b" (bad)	This particular feature was weak or missing in my graduate program.
"d" (desirable)	A general comment that this feature is a desirable component of a good Ph.D. program.
"g" (good)	I was generally pleased by the way this feature was covered in my graduate program.

Of course, other areas were the subjects of comments, but their frequency was not sufficient to reach our somewhat arbitrary 6% cutoff. Nonetheless, some respondents held strong opinions on these minority subjects, and a few of these views will be included in the text of the report.

Categories of comments. Descriptions of the 11 most frequently mentioned categories are given in Table 7. Designation of the subcategories as "b", "d", and "g" was sometimes difficult to achieve with precision. Nevertheless, it is hoped that these descriptors will give at least a rough idea of the nature of the comments that were received.

Examination of all responses. Figure 3 is a graphical representation of the comments of the 978 respondents who wrote comments. The data are also listed in Table 8. In Figure 3, the bars have been segmented to show the percentage of "g", "d", and "b" comments. The percentages refer to the fraction of the total respondents (2381) that mentioned a particular category of comment. The three categories having to do in some way with preparation for a career in industry represent "hot spots" in the responses. These three (categories 1–3) were mentioned by 4.5% or more of those providing written comments. The almost total absence of comments indicating that this was a good feature ("g") in the graduate experience (0.0%, 0.3%, and 0.0%, respectively) shows strikingly that those making comments almost universally believe that their Ph.D. education did not provide adequate preparation for a career in industry.

"*The single most important thing your committee can do is to help faculties recognize that industrial work, while different from academic work, is equally demanding, creative, rewarding, and is a first-class career choice!*"

Ph.D. chemist in industry

"*My department treated its graduate students quite poorly, in my opinion. Although it is a prestigious …university, the training was very much individual sink-or-swim and really did not prepare us very well for life after graduate school. I left not knowing how to write a proposal, never giving a formal presentation, with no sense of the politics and ways of real science.*"

Ph.D. chemist in industry

Another frequently mentioned topic was the research advisor (category 4; 4.5%). This is perhaps not surprising as the advisor is the person in the program with whom the Ph.D. student works most closely and intensively. Many respondents (1.6%) reported that their experience with the research advisor was good, but an even larger fraction (2.1%) commented that there were problems with this aspect of the Ph.D. program. The remainder (0.8%) simply commented that having a good advisor was important.

Other categories mentioned by around 4% of the respondents were interdisciplinary studies (category 6) and emphasis on breadth rather than specialization (category 5). Of those commenting about the interdisciplinary aspects of the Ph.D. program, one-third reported a good experience in this regard, and only about 20% commented that this feature should not have been a part of their own studies. The largest fraction of those

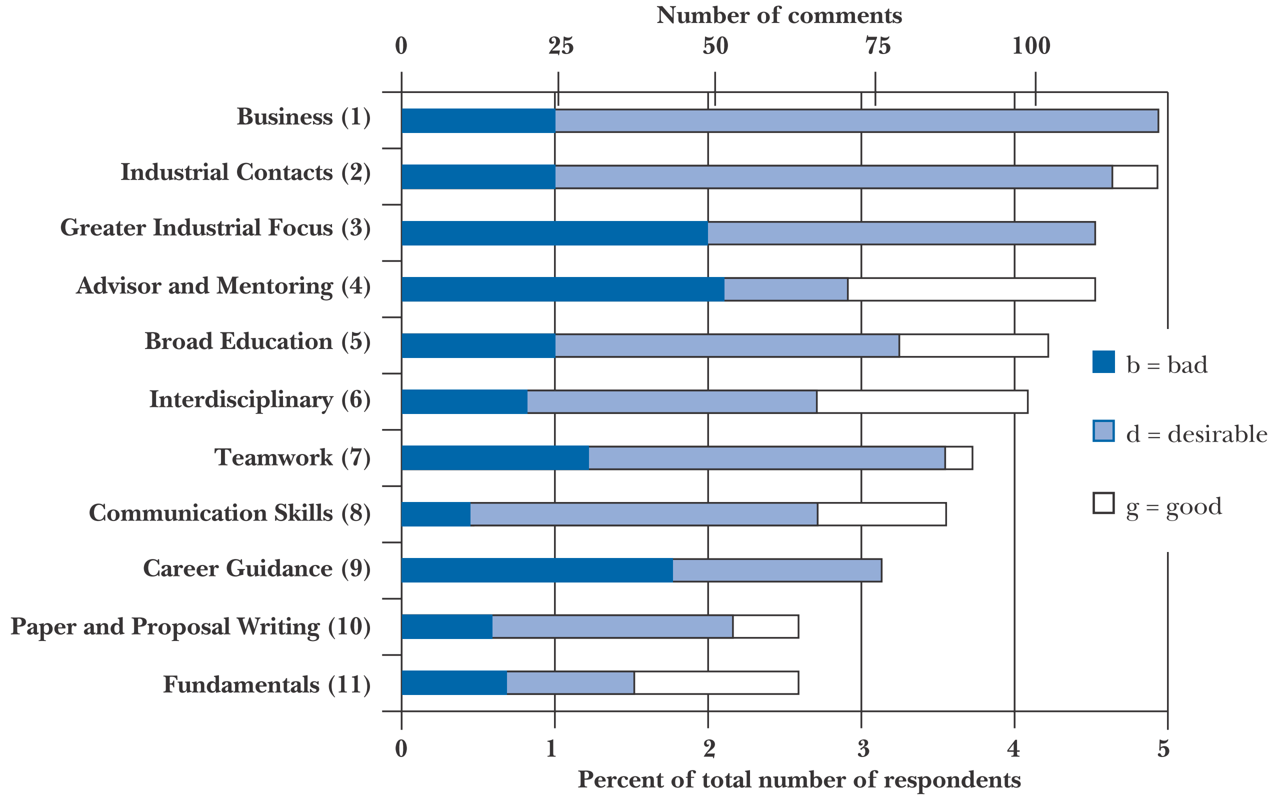
Table 7. Categories of Comments That Were Most Frequently Mentioned

1. Courses or other preparation concerning business aspects of a career in chemistry
2. Contacts and interaction with industry
3. Greater emphasis on preparation for an industrial career as opposed to an academic career
4. Effective Ph.D. advisor
5. A broad as opposed to specialized education
6. Emphasis on and experience in interdisciplinary research
7. Teamwork
8. Development of oral and written communication skills
9. Career information and guidance
10. Experience and training in writing papers and proposals
11. Emphasis on the fundamentals of chemistry

Subcategories

"b" (bad)	This particular feature was weak or missing in my graduate program.
"d" (desirable)	A general comment that this feature is a desirable component of a good Ph.D. program.
"g" (good)	I was generally pleased by the way this feature was covered in my graduate program.

Figure 3. Percent and absolute number of total respondents commenting on topics in various categories, with designation of the nature of the comments as "b", "d", or "g"



commenting in this area (about half) simply suggested that this aspect should be a part of a good Ph.D. program. Concerning breadth versus specialization, equal fractions (about one-fifth) of those commenting in this area reported this to be a good or bad feature of their own programs, whereas the remaining 60% simply felt that Ph.D. programs tended to be too specialized. It is worth noting that this breadth-versus-specialization question is in a sense the opposite side of the coin compared with category 11 (emphasis on fundamentals), a category mentioned by 2.6% of the respondents. To a certain degree, those advocating less specialization and those wanting to emphasize the fundamental core of the science are two groups pulling in opposite directions. Support for the assertion that there are two groups among those making comments in categories 6 and 11 is found in the fact that of the 152 individuals making comments in these categories, only 9 (6%) made comments in both. The remaining 94% fell into two groups, each of which made comments in only one of the two categories.

> "*In my case, more exposure to industry and industrial chemistry would have been very helpful.... The university that I attended resisted collaborative projects with industrial and government labs.*"
>
> Ph.D. chemist from "thirties group"

> "*What I found most admirable about my Ph.D. training experience was that my advisor had my education in mind, not his publication list. When he felt that I had learned all that I could from the program, I defended and that was that.... Yet, having recently served on a search committee, I saw students with 10, 15, 20 or more papers from their Ph.D. work. I cannot believe that this is serving the student's interest, only the advisor's.*"
>
> Ph.D. chemist from "forties group"

Three categories mentioned by 3–4% of the respondents were categories 7 (teamwork; 3.7%), 8 (communication skills; 3.5%), and 9 (career information; 3.1%). It may be significant that virtually no respondents reported that teamwork and career information were strong points in their graduate programs. However, in the area of communication skills, more of the respondents reported good preparation (23%) than those who felt that their education was weak in this respect (15%). Finally, a significant number of individuals commented on the desirability of having experience in writing papers and research proposals.

Comparison of comments from different groups: those employed in industry compared with those in

Table 8. Tabulation of Comments According to Category with Industry/Academia Comparison[a]

Category[b]	Subcategory[b]	All Comments Number (percent)	Comments from Ph.D. Chemists in Industry Compared with Those in Academia: Industry Number (percent)	Academia Number (percent)
1. Business	d	93 (3.9%)	81 (5.7%)	3 (0.6%)
	g	1 (0.0%)	1 (0.1%)	0 (0.0%)
	b	25 (1.0%)	19 (1.3%)	2 (0.4%)
2. Industrial Contacts	d	86 (3.6%)	70 (5.0%)	7 (1.4%)
	g	8 (0.3%)	6 (0.4%)	2 (0.4%)
	b	25 (1.0%)	23 (1.6%)	1 (0.2%)
3. Greater Industrial Focus	d	59 (2.5%)	51 (3.6%)	5 (1.0%)
	g	1 (0.0%)	1 (0.1%)	0 (0.0%)
	b	47 (2.0%)	40 (2.8%)	4 (0.8%)
4. Advisor and Mentoring	d	19 (0.8%)	12 (0.9%)	5 (1.0%)
	g	39 (1.6%)	27 (1.9%)	8 (1.6%)
	b	50 (2.1%)	23 (1.6%)	17 (3.4%)
5. Broad Education	d	55 (2.3%)	35 (2.5%)	9 (1.8%)
	g	22 (0.9%)	12 (0.9%)	9 (1.8%)
	b	23 (1.0%)	17 (1.2%)	4 (0.8%)
6. Interdisciplinary	d	46 (1.9%)	35 (2.5%)	7 (1.4%)
	g	33 (1.4%)	21 (1.5%)	7 (1.4%)
	b	18 (0.8%)	18 (1.3%)	0 (0.0%)
7. Teamwork	d	55 (2.3%)	47 (3.3%)	4 (0.8%)
	g	5 (0.2%)	5 (0.4%)	0 (0.0%)
	b	28 (1.2%)	25 (1.8%)	3 (0.6%)
8. Communication Skills	d	52 (2.2%)	43 (3.0%)	7 (1.4%)
	g	19 (0.8%)	12 (0.9%)	3 (0.6%)
	b	13 (0.5%)	9 (0.6%)	4 (0.8%)
9. Career Guidance	d	34 (1.4%)	23 (1.6%)	5 (1.0%)
	g	0 (0.0%)	0 (0.0%)	0 (0.0%)
	b	41 (1.7%)	22 (1.6%)	11 (2.2%)
10. Paper and Proposal Writing	d	36 (1.5%)	25 (1.8%)	9 (1.8%)
	g	11 (0.5%)	6 (0.4%)	3 (0.6%)
	b	14 (0.6%)	9 (0.6%)	1 (0.2%)
11. Fundamentals	d	19 (0.8%)	13 (0.9%)	4 (0.8%)
	g	26 (1.1%)	17 (1.2%)	8 (1.6%)
	b	16 (0.7%)	2 (0.1%)	11 (2.2%)

[a] Percentages are computed from the total number of respondents in a given class. For example, to compute the percent commenting in a given area for those in academia, the number of comments made by academics was divided by 5.04 (504 from academia returned the questionnaire; of those, 208 made comments).
[b] See Table 7 for definition of subcategories.

academia. The responses of the industrial group (655 of those making comments) and the academic group (208 of those making comments) are presented in Table 8.

"*Your survey is skewed in the wrong direction. Most of what I know I taught myself. The job of an educator is to get the student to the point at which he/she can pick up on anything related to chemistry.*"
Ph.D. chemist in academia

"*The part of my graduate training in which I feel deficient is in original thought and problem solving. My advisor set out the experiments exactly,* *and I was not required very often to direct my research, which is the skill I need in my job and have learned on the job.*"

Ph.D. chemist in industry

As pointed out earlier, categories involving proper preparation of students for careers in industry (categories 1–3) drew the most comments from the entire group of respondents. As might be expected, these high rates of response are due mainly to those in the industrial group, who were much more likely to mention these categories than their academic counterparts. These trends will be illustrated by discussion of the ratios of frequency of response of the two groups (see box for definitions). The industry-to-academic ratio was 6.4 for category 1 (preparation for business aspects of a career in chemistry), 3.2 for category 2 (industrial contacts), and 3.1 for category 3 (greater emphasis on industrial careers instead of academic). The importance of teamwork was stressed by the industrial cohort (category 7; ratio 3.5), as was the importance of interdisciplinary education (category 6; ratio 1.7). Very few of the comments from either group fell in the "g" subcategory. These results serve to reemphasize the principal conclusion of the statistical analysis in Part 1 of this report, viz., Ph.D. chemists working in industry are much more likely to be dissatisfied with one or more aspects of their Ph.D. education than are those in academia.

"*My graduate institution did not have a committee to follow the students' progress. Hence, many students are taken advantage of by their mentors.*"

Ph.D. chemist in industry

"*Chemistry departments should not encourage students to major in fields or do research in areas where they know there are limited job opportunities.*"

Ph.D. chemist in industry

In two categories the academic cohort was significantly more likely to comment than the industrial group. The ratio of the fraction of academics commenting about emphasis on fundamentals (category 11) to the fraction of industrial people commenting was 2.3, and the academic group was 1.5 times more likely to comment about the research advisor. In this regard, it is perhaps slightly surprising that the academic group was much more likely to report that the advisor was ineffective ("b"; ratio 2.3). In all of the other categories, the frequency and pattern of responses were fairly similar in the two groups.

Ratio = $\dfrac{\textbf{frequency of comment by group Y}}{\textbf{frequency of comment by group Z}}$

Ratios to be discussed: $\dfrac{\textbf{Industrial}}{\textbf{Academic}}$; $\dfrac{\textbf{Women}}{\textbf{Men}}$; $\dfrac{\textbf{"Thirties"}}{\textbf{"Forties"}}$

Comparison of comments from different groups: women and men. Just as was found in the statistical analysis of the responses (Part 1 of this report), there were relatively few differences in the frequency and pattern of the comments received from women and men. The data are presented in Table 9. There also was no significant difference between the gender composition of the Ph.D. chemists who returned the questionnaire (24% women) and those who also wrote comments (26% women). If in each of the categories the total frequency of comment by women is divided by the total frequency of comment by men, one finds that 6 of the 11 categories have ratios falling between 0.8 and 1.2, i.e., the comment rates for the two groups were very similar.

By contrast, women were 50% more likely to write comments about the importance of fundamentals (category 11), 40% more likely to comment about the importance of writing papers and proposals (category 10), and 30% more likely to comment about the importance of communication skills (category 8). However, in each of these categories, the general pattern ("g" : "d" : "b") of comments was very similar for men and women.

Women were 50% more likely to comment about the interdisciplinary aspects of the Ph.D. program (category 6). Those making comments about the importance of fundamentals (category 11) and those emphasizing the importance of interdisciplinary study (category 6) can be regarded as two groups with somewhat opposing views. Support for this assertion can be found in the fact that of the 148 individuals who made comments in categories 6 and 11, only 10 (7%) made comments that fell in both categories. The remaining 93% fell into two groups, each of which made comments in only one of these two categories.

"*Secondly, the Ph.D. advisor is crucial! The advisor should be a hands-on, active mentor. My advisor was excellent and I learned a great deal from him. This is not always the case with other Ph.D. advisors at many institutions.*"

Female Ph.D. in academia

"*There should be more emphasis on a student developing his/her own interests related to chemistry and less on satisfying the research advisor. Maybe if there were alternative funding sources for stipends, this could be encouraged. I would have benefited from more direct help with writing proposals and making professional contacts.*"

Female Ph.D. in academia

The category of research advisor was also more frequently commented upon by women than by men. Strikingly, women were almost twice as likely to make unfavorable comments about their own research advi-

Table 9. Tabulation of Comments According to Category with Women/Men and "Thirties"/ "Forties" Comparisons[a]

Category	Subcategory	Comments from Women Compared with Those from Men		Comments from the "Thirties Group" Compared with Those from the "Forties Group"	
		Women Number (percent)	Men Number (percent)	"Thirties" Number (percent)	"Forties" Number (percent)
1. Business	d	19 (3.4%)	74 (4.2%)	48 (3.9%)	45 (3.9%)
	g	0 (0.0%)	1 (0.1%)	0 (0.0%)	1 (0.1%)
	b	9 (1.6%)	16 (0.9%)	9 (0.7%)	16 (1.4%)
2. Industrial Contacts	d	21 (3.8%)	65 (3.7%)	41 (3.3%)	45 (3.9%)
	g	3 (0.5%)	5 (0.3%)	5 (0.4%)	3 (0.3%)
	b	3 (0.5%)	22 (1.2%)	10 (0.8%)	15 (1.3%)
3. Greater Industrial Focus	d	9 (1.6%)	50 (2.8%)	41 (3.3%)	18 (1.6%)
	g	0 (0.0%)	1 (0.1%)	0 (0.0%)	1 (0.1%)
	b	18 (3.2%)	29 (1.6%)	27 (2.2%)	20 (1.7%)
4. Advisor and Mentoring	d	5 (0.9%)	14 (0.8%)	9 (0.7%)	10 (0.9%)
	g	12 (2.2%)	27 (1.5%)	27 (2.2%)	12 (1.0%)
	b	20 (3.6%)	30 (1.7%)	38 (3.1%)	11 (0.9%)
5. Broad Education	d	15 (2.7%)	40 (2.3%)	31 (2.5%)	24 (2.1%)
	g	6 (1.1%)	16 (0.9%)	9 (0.7%)	13 (1.1%)
	b	4 (0.7%)	19 (1.1%)	15 (1.2%)	8 (0.7%)
6. Interdisciplinary	d	17 (3.1%)	29 (1.6%)	30 (2.4%)	16 (1.4%)
	g	11 (2.0%)	22 (1.2%)	22 (1.8%)	11 (0.9%)
	b	5 (0.9%)	13 (0.7%)	8 (0.6%)	10 (0.0%)
7. Teamwork	d	15 (2.7%)	40 (2.3%)	22 (1.8%)	33 (2.8%)
	g	1 (0.2%)	4 (0.2%)	3 (0.2%)	2 (0.2%)
	b	7 (1.3%)	21 (1.2%)	14 (1.1%)	14 (1.2%)
8. Communication Skills	d	14 (2.5%)	38 (2.2%)	24 (1.9%)	28 (2.4%)
	g	6 (1.1%)	13 (0.7%)	12 (1.0%)	7 (0.6%)
	b	6 (1.1%)	7 (0.4%)	8 (0.6%)	5 (0.4%)
9. Career Guidance	d	10 (1.8%)	24 (1.4%)	22 (1.8%)	12 (1.0%)
	g	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
	b	12 (2.2%)	29 (1.6%)	27 (2.2%)	14 (1.2%)
10. Paper and Proposal Writing	d	12 (2.2%)	24 (1.4%)	19 (1.5%)	17 (1.5%)
	g	4 (0.7%)	7 (0.4%)	5 (0.4%)	6 (0.5%)
	b	4 (0.7%)	10 (0.6%)	11 (0.9%)	3 (0.3%)
11. Fundamentals	d	6 (1.1%)	13 (0.7%)	15 (1.2%)	4 (0.3%)
	g	9 (1.6%)	17 (1.0%)	17 (1.4%)	9 (0.8%)
	b	6 (1.1%)	10 (0.6%)	13 (1.0%)	3 (0.3%)

[a]See Table 8 for explanation of percentages.

sor than were men (category 4; "b"). This is completely consistent with the results of the statistical analysis reported in Part 1, where the overall evaluation of the effectiveness of the research advisor was significantly lower for female than for male respondents.

Comparison of comments from different groups: "thirties group" and "forties group". As pointed out earlier, the survey was conducted with two groups of identical size, one composed of Ph.D. chemists who were 33–37 years of age in 1998 and the other of those who were 43–47 years. For lack of better terminology, these have been called the "thirties group" and the "forties group". The average date of completion of the Ph.D. was 1991 for the "thirties group" and 1981 for the "forties group". Thus, examination of the responses of the two groups could offer insight into how Ph.D. education and the students' perception of it changed over the period of a decade.

The statistical analysis of the responses of these two groups that was reported in Part 1 did reveal some significant differences, but these were fewer in number and in degree than the differences between academic and industrial chemists. An important difference that was found between the "thirties group" and the "forties group" was that the members of the former were much more likely to report that they would have benefited from more courses in chemistry.

> ". . . *two to eight formal courses were required. I took nine and audited another. I now teach a large variety of undergraduate chemistry courses and am grateful for my broad academic background.*"
>
> Ph.D. chemist from the "thirties group"

> "*We were not required to take any formal classes—it was actually discouraged. This I think is wrong.*"
>
> Ph.D. chemist from the "thirties group"

In considering the comments, once again there were many categories where the frequency of comment was almost identical for the two groups. The data are summarized in Table 9. The ratio of the fraction of the "thirties group" commenting to the fraction of the "forties group" doing so was computed for each category. The ratio fell between 0.8 and 1.2 for 4 of the 11 categories, whereas it was just a little outside this range for category 10 (writing papers and proposals; ratio 1.26) and category 7 (teamwork; ratio 0.74).

The largest difference was found for category 11 (fundamentals; ratio 2.6), where the "thirties group" was much more likely to comment than their older counterparts. A significant number of these comments called for an increase in the number and diversity of chemistry courses that are required in the program. The importance of the advisor (category 4; ratio 2.1) was also stressed more frequently by the "thirties group". Those commenting that their own advisors had been effective ("g"; ratio 2.2) were less numerous than those whose experience was not satisfactory ("b"; ratio 3.2). So, the "thirties group" cited good and bad advisors more frequently than the "forties group", but the latter type of comment was dominant.

> "*As a recruiter for new Ph.D.s entering the pharmaceutical industry, technical competence is certainly very important. However, my personal experience in industry and as a recruiter has shown that teamwork and people skills can make or break a hiring or promotion decision.*"
>
> Ph.D. chemist from "thirties group"

> "*My advisor was a b.....d in some respects, but he taught unambiguously the differences between good and bad data, strong and weak conclusions, and the value of polished presentation skills. These have served me well in my industrial career.*"
>
> Ph.D. chemist from "thirties group"

Career advisement (category 9) drew more comments from the "thirties group" (ratio 1.8). No comments were complimentary ("g") in this area, and the comment rate of the "thirties group" compared with the "forties group" was about equal for comments that career advisement was weak or ineffective ("b") and for comments that this aspect is a desirable part of a good Ph.D. program ("d"). Members of the "thirties group" were also more likely to comment that the Ph.D. program should emphasize industrial aspects as opposed to preparation for academic careers (category 3; ratio 1.6). The difference was largely in the area of those who commented that it would be desirable ("d") for programs to move in this direction.

Finally, the "thirties group" was 50% more likely to comment about the desirability of interdisciplinary education and research (category 6). The younger cohort was twice as likely to comment that their program was satisfactory in this area, a finding that may reflect an increase in the number of students participating in interdisciplinary projects.

Examples of suggestions made by respondents. A few examples of specific suggestions will be listed. They are not exact quotations but have been paraphrased extensively. The suggestions are organized according to the 11 categories of comment.

- Encourage or at least allow those students preparing for a career in industry to take courses in such areas as business, project management, finance, accounting, patent law, industrial/process chemistry, experimental design, and chemical engineering.
- Teach some of the topics listed in the first suggestion in the form of ACS-type minicourses.
- Develop industrial internships for graduate students.
- Appoint successful industrial chemists as adjunct professors to give advice to students and lectures on careers in industry.
- Provide two or more distinct tracts for the Ph.D., including at least programs for those interested in industrial careers and those headed for academia.
- Invite more industrial chemists to present seminars.

- Include industrial chemists as active members of Ph.D. advisory committees.
- Encourage faculty to devote a larger fraction of their efforts to teaching their graduate students in both courses and research.
- Be certain that, in both courses and research, a Ph.D. student is not restricted to a single narrow specialization.
- Too much of the student's education is in the hands of the research advisor. Develop mechanisms through which other faculty are actively involved in the process. Strengthening and redefining the function of the advisory committee are a possible route.
- Provide a mechanism that will make clear the relationships of the student's thesis research to other areas of both an applied and fundamental character, i.e., try to provide the "big picture".
- Develop more interdisciplinary research projects with involvement of several faculty, both chemists and others, in guiding the research work of the student.
- Emphasize the importance of teamwork and, if possible, expose the students to the concepts and practice of teamwork, e.g., group activities directed toward solving a common research problem.
- Be certain that each student has several opportunities to make oral presentations during the Ph.D. program. These can include lectures on the current literature, the student's own thesis research, a research proposal, and presentations at scientific meetings.
- Offer a special short course in the art of making effective oral presentations.
- Be certain that each student is trained in technical writing. This might include the composition of an original research proposal, writing of research results for publication, and, of course, the preparation of the Ph.D. dissertation. Active faculty participation is essential.
- Develop mechanisms for providing realistic and up-to-date information about careers for Ph.D. chemists.
- Provide formal and organized assistance to students seeking employment.
- Return to the fundamentals. Challenge the student to become an expert in his or her field.

Obviously, some of the above comments tend to contradict others, but this simply reflects the fact that they originated from individuals with different opinions. Thus, this survey does not provide a blueprint for restructuring Ph.D. education in chemistry. Rather, it gives faculties and other interested parties an overview of the opinions of students who have received Ph.D. degrees from the universities of this country. Perhaps some of these comments and suggestions will provide the spark needed to initiate significant improvements in our graduate programs.

References

1. (a) *Chemical & Engineering News* **1947**, *25*, 1934–1936; 2010–2013; 2076–2081. (b) *Chemical & Engineering News* **1957**, *35*, 56–60; 65–67. (c) *Chemical & Engineering News* **1964**, *42*, 76–84. (d) *Chemical & Engineering News* **1972**, *50*, 35–39. (e) *Chemical & Engineering News*, April 28, 1975, 38–42.
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