The training, careers, and work of Ph.D. physical scientists: Not simply academic

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(Received 5 December 2001; accepted 5 August 2002)

We present an in-depth portrait of the training, careers, and work of recent Ph.D. physical scientists. Use of specialized training varies widely, with about half often using knowledge of their Ph.D. specialty area in their jobs. The use of specialized training does not, however, correlate with job satisfaction. In this and other important measures, there are relatively few differences between “academics” and “nonacademics.” Important job skills for all employment sectors include writing, oral presentation, management, data analysis, designing projects, critical thinking, and working in an interdisciplinary context. Rankings given by respondents of graduate training in some of these skill areas were significantly lower than the importance of these skills in the workplace. We also found that the rated quality of graduate training varies relatively little by department or advisor. Finally, although nonacademic aspirations among graduate students are fairly common, these do not appear to be well supported while in graduate school. © 2002 American Association of Physics Teachers. [DOI: 10.1119/1.1510884]

I. BACKGROUND

Ph.D. scientists are widely perceived to be an important component of the science workforce. Although the role of the academic professorate has been widely studied, the work activities, training, and attitudes of Ph.D. scientists in general have received less attention. In addition, recent changes in the economy have altered the employment patterns and work environments for Ph.D. scientists. Better understanding of the relationship between graduate training and the subsequent careers of Ph.D. scientists will shed light on the relevance of the graduate training system to the U.S. economy. This topic is also important given the substantial federal investment in the education of Ph.D. scientists, which in the mid-1990s was estimated by the NSF to be about a quarter of a billion dollars a year for physical scientists alone.

Although statistics on the doctoral workforce have long been available, there has been relatively little quantitative research on the match between training and jobs. The primary source of information on the doctoral science workforce in the United States is the biennial Survey of Doctoral Recipients (SDR). The SDR reports if respondents characterize the relationship between graduate training and work as “closely,” “somewhat,” or “not related.” Other surveys have categorized respondents as either “in” or “out” of their field. The SDR also reports on employment status, sector of employment, and related statistics. Information on work activities is primarily in categories such as “basic research,” “applied research,” “development,” “management,” and “teaching.” These are rather general categories, which lead to only limited understanding of how individuals use their training.

One of the few studies that contain detailed information about work activities examined a cohort of physics bachelor degree holders, many of whom obtained higher degrees. At all degree levels, problem solving, interpersonal skills, advanced computer skills, and technical writing are commonly used by physics degree holders working in industry and national laboratories. Those who later obtained Ph.D. degrees working in these sectors were distinguished, in particular, by a greater use of knowledge of physics, although the sample size was small. Other studies have examined postdoctoral experiences and the employment status of recent graduates.

Many questions remain, however, about the graduate training and the occupational experiences of Ph.D.’s, including the match between graduate goals, training and later job outcomes, particularly for nonacademic careers. We will specifically examine job satisfaction, which is arguably one of the most important indicators of the “success” of graduate training. Our new study addresses these issues through a combination of qualitative and quantitative methods.

II. Ph.D. CAREERS PROJECT

The Ph.D. Careers Project was designed to provide an in-depth portrait of the careers and work of Ph.D. physical scientists. The study cohort consisted of all 1990–1994 physical science graduates (chemistry, physics, atmospheric sciences, astronomy, and related fields) from eight medium- to large-sized universities. The time frame was chosen so that the respondents were approximately four to eight years beyond receipt of their Ph.D.—a point at which most are seeking, or have found, relatively stable employment beyond initial temporary positions.

Analysis of 46 minimally structured, in-depth interviews was used to guide construction of a survey. This study is based on ethnographic methods and our data gathering was, therefore, not guided by a priori theoretical expectations. The survey contained sections on graduate experience, career path, current position, relationship to training, position stability, aspirations and job satisfaction, and demographics. Our data consist of 714 completed surveys, which were initially sent out in fall 1998, representing a 65% response rate. Most of the results from our survey are on a “Likert-type” scale, which allows a greater level of detail and nuance than the categorical answers used in many surveys. Our sample consists of 55% chemistry graduates, 33% physics graduates, and 12% from other departments.
The largest group of our respondents were employed in business or industry (44%), with a quarter (25%) employed in a college or university. Almost another quarter (23%) were employed in some sort of research laboratory. This last category is comprised of 13% in government research laboratories, 7% in university-affiliated research institutes, and 3% in nonprofit research institutes. The remaining 7% were employed in a variety of other sectors, including 2% who are self-employed. Not included above are the 4% of all respondents who were not employed.

This distribution is similar to that of the national sample in the 1997 SDR. For 1990–1994 graduates the 1997 SDR finds 42% employed in educational institutions, 49% employed in private industry, and 8% employed by the government. The smaller percentage employed by universities in our sample is likely due to the different categories used. This overall similarity indicates that the results from the mid-sized sample here are likely to be more generally applicable.

We present below data on job satisfaction, aspirations, work activities, graduate training, employment characteristics, and the relationships between these variables. These results are meant to help guide graduate students, educational institutions, and policy makers. Further results from this project will be reported elsewhere. We first examine graduate student experiences and aspirations. We then continue with a discussion of the jobs graduates obtain.

### III. GRADUATE EXPERIENCES AND ASPIRATIONS

When asked about their overall level of satisfaction with their graduate experience, three quarters (75%) of our sample responded positively and a quarter were either dissatisfied or neutral (Table I). About one-third (32%) responded that they were “very satisfied.” We found no difference in graduate satisfaction between physicists or chemists as a group and little difference between departments.

We begin with an examination of graduates’ career goals. Our initial interviews indicated that many did not have clear career goals when they entered graduate school. This finding was verified by the survey, which found that about half (52%) reported having “vague” or no career goals when they began their Ph.D. studies. Only one in five (22%) reported that they had “definite” career goals at that time, with the remainder reporting that they had some career goals. This lack of career goals implies that it may be difficult to target training activities toward a specific type of career. Even at the time of the survey, four to eight years after graduation, one in five (19%) report vague or no career goals.

Independent of the level of certainty of career goals, we also examined the extent to which respondents aspired to academic careers at Ph.D. completion (Table II). Responses ranged from 19% who said they had no academic aspirations at the time they obtained their Ph.D. to 18% who said that an academic career was their only aspiration. In our qualitative (interview) data we found examples of those for whom academics was not an aspiration at any point in graduate school and examples of those who initially aspired to an academic career, but who, as described by one respondent, “came away from grad school very disillusioned with large research universities.”

We also asked if “obtaining a Ph.D. was a goal in and of itself as compared to a pragmatic goal” (Table II). The largest response was the 42% who answered “both equally.” The remainder were split between those with more pragmatic motivations and those who viewed the Ph.D. as an intrinsic goal, with a slightly greater percentage in the latter category (35% answered 1 or 2; Table II). As the level of pragmatism increased, so did the percentage who reported having more definite career goals when entering graduate school. There was no relationship, however, between pragmatism and the degree of academic aspiration at graduation.

We also found that those who reported the highest level of pragmatism were more dissatisfied with their graduate experience. This finding would appear to indicate that those who expected their Ph.D. to be directly applicable to their subsequent career were more likely to be disappointed in their graduate education. Those with more definite career goals in general, however, were not more dissatisfied with their graduate experience. These two results, taken together, indicate that holding pragmatic expectations resulted in lower satisfaction with graduate school, rather than the presence of more definite goals against which success could be measured.

In summary, we have found that, as a group, physical science Ph.D. recipients have a broad range of career goals upon graduation, ranging from about a fifth who “did not at all” aspire to an academic career to those for whom this was their “only aspiration” (Table II). Further, for the majority of our cohort, pragmatic reasons play an important part in the motivation to gain a Ph.D. This finding is supported by our qualitative data, which indicate that a range of aspirations are present in the graduate student population.

This result stands in contrast to the common perception that most physical science Ph.D. graduates aspire to academic careers. We found evidence for this in our interview data, with some interviewees indicating that pursuing an academic career was viewed as “pretty much a singular path almost without exception” or that they “[didn’t] know anybody from my class who has not at least started out pursuing an academic path.” Given this contrast, we will examine our results for aspirations at graduation in the context of related results from other studies. We perform this comparison because one possible explanation for this apparent discrepancy is that the nonacademic career aspirations reported in our data is retrospective modification, where the respondent’s report of (or memory of) past aspirations are modified in order to better match his/her current circumstance (because many are not employed in an academic setting).

Most of the information on aspirations in other studies is
in the form of categorical data in which respondents were asked to identify either single or multiple career aspirations. Although a Likert-style scale, as used here (for example, Table II), is a more sensitive indicator of aspirations, it is still useful to examine the existing categorical data to determine if these data are consistent with our results. In particular, we wish to determine if there is evidence for large changes in aspirations over time, from graduate school through to the early career period examined in this study.

Our findings are broadly comparable to results from the “Ph.D.’s—Ten Years Later” study, which surveyed different fields and used a different question design.10,23 This study is also retrospective. These data show only a small overall change in aspirations through graduate school for those who began with some definite aspiration.24 Their data also show a significant drop in the percentage with “no specific career goals” with time. A decrease in those with “vague or no career goals” is also seen in our results, as reported above, which represent a comparison over the period from graduation to early career instead of from the beginning to end of graduate school.

We also can compare our findings with two contemporaneous surveys of graduate students. For B.S. physicists heading toward graduate studies in 1998, the AIP reports that 60% aspire to “college/university teaching and research” positions,25 which appears to be consistent with our results.26 Golde and Dore, in a survey of graduate students, also found results similar to ours for the academic career aspirations of chemistry graduate students.27,28

The data reviewed above, when combined with our results, give no indication of large changes in the direction of specific aspirations with time, although aspirations do become better defined. We conclude that our retrospective data offer a reasonably accurate portrait of the past aspirations of our Ph.D. cohort and that nonacademic career aspirations are, indeed, common among graduate students.

We hypothesize that, while many graduate students contemplate nonacademic careers, these aspirations are not communicated to others because of the emphasis on academic career paths within the academic culture. This lack of communication may be because the culture in most graduate programs so strongly emphasizes the attainment of an academic position that aspiring to any other goal is, as one interviewee put it, “reaching for something lesser.” Part of this perception may be because goals, in general, are not being discussed as a matter of course (Ref. 2, p. 106) and because there is a specific lack of support for nonacademic goals. There is evidence for a lack of support for nonacademic careers in our interview data (along with comments written on surveys), where a number of interviewees noted that there was little support for nonacademic career aspirations in their graduate departments.

I have had a very rewarding, research intensive, career in my field... my decision to accept an industrial research position was literally scorned by advisors and faculty... A change in the “academic” career bias would help both individuals and institutions alike (astronomy graduate).

They [graduate advisors] don’t have a concept of jobs other than academics (chemistry graduate).

Graduate school did not give me any training [for] pursuing a career outside of academia...

In fact, there did not seem to exist any mechanism whereby a student... could be made aware of various options and come up with a job search strategy (physics graduate).

I think in the sciences, we were perhaps not told directly, but it was... an implied thing, that there was one [career] path... big people at [the university] were very, very supportive of people who went academic routes, and they were lukewarm... if they pursued anything that was nonacademic (chemistry graduate).

Overall, I feel graduate school does a poor job of preparing one for industry/business. It is very narrowly focused in preparing people for graduate level academic jobs (chemistry graduate).

It is assumed all through your training that you will go into academics and other options are not discussed (chemistry graduate).

We note, however, that some of our respondents did find support for nonacademic career aspirations.

The experience that [my advisor] brought to the lab and the progress of [the advisor’s] former students were both gearing me for an industrial position, as opposed to academic (physics graduate).

My final Ph.D. advisor saw pretty clearly that... applied science was my forte and supported me in it (physics graduate).

My graduate advisor was particularly instrumental in developing, honing and preparing me for my [industrial] career (chemistry graduate).

However, overall, it would appear that support for nonacademic careers is limited for many, if not most, physical science graduate students so that, while many graduates have nonacademic career aspirations, these aspirations do not appear to have been shared with fellow students.

The implications of these results for graduate education will be discussed later. We now turn to the careers and work of these graduates. We first examine job stability and then move to work activities, the relationship between graduate training and work activities and, finally, job satisfaction.

IV. POSITION STABILITY

One point of particular interest is the job stability of Ph.D.’s. Job stability immediately after graduation is an important issue when considering the transition from formal education to the work world. The recruitment and retention of students is, presumably, affected by job stability, and, as we show later, job stability is a factor in job satisfaction.

The first question to address is how to measure job stability. To shed light on this methodological question, we addressed this issue in two ways. First, we asked respondents to report the number of years that they had spent in either temporary or permanent positions and the type of employer (industry, college or university, government research lab, etc.). We defined a “temporary” position with an operational definition of a position with “an end date or fixed term,” similar to that of other recent surveys.29 We were concerned that some respondents would be unable to label their position
as either “temporary” or “permanent,” so we provided a third category of “unable to classify.” Only 6%, however, used the “unable to classify” category.

Over 60% held a temporary position immediately following graduate school. Half of these were held for more than two and a half years. Holding of a temporary position did not correlate with later skill use; that is, those that held a temporary position after graduation were no more or less likely to often use their specialized training in their eventual position as compared to those who did not hold a temporary position after graduate school. We found that labels such as “permanent” and “temporary” did not correlate well with job stability four to eight years past graduation. We measured job stability more directly by asking respondents to judge the probability that they would have the option of continuing with their current employer for the next five years. A majority reported a high level of job stability, with 53% reporting a “strong” chance of having the option of continuing; and a further 20% rated their job stability as four on the five point scale. Only 15% rated their job stability as low (1 or 2). The answers to this question were similar across sectors (for example, industry, academic, government laboratory). These percentages held even for academia as a whole, with tenure-track faculty generally rating their job stability as high, which was offset by low job stability ratings from nontenure track employees of colleges and universities (about one-third of those employed in academia).30

A quarter (25%) of the respondents reporting had only one employer before graduation and nearly half (45%) have had only two employers since graduation. A scant 10% have had four or more employers since graduation. These results strengthen the conclusion that most Ph.D.’s have relatively stable positions four to eight years following graduation. However, a significant percentage have recently changed jobs: 30% have been with their current employer for two years or less as of the survey date. We also found that 15% of those currently working had experienced a break of more than three months in their employment at some point since graduation.31 These data may be less an indication of dissatisfaction with positions held, given the large percentage initially working in “temporary” positions, and more an indication of the timing of their transitions to more “permanent” positions.

V. Ph.D.’s AT WORK

We now examine the nature of Ph.D. work, which will provide the context for a discussion of the relationship between work and graduate training. We will examine many aspects of the work of Ph.D. physical scientists including specific work activities and types of knowledge used.

We first examine what is probably considered the prototypical activity of Ph.D. scientists: research and/or development (R&D). We found a range of responses regarding the amount of time spent doing R&D (see Table III): from only 14% who reported that they spent no time doing R&D to 33% who reported spending all their time performing R&D. As might be expected, R&D can be considered a fairly typical activity of Ph.D. physical scientists, with 69% reporting that they spend at least half their time performing R&D and related activities.

Of particular interest is the use of specialized Ph.D. knowledge. Our respondents reported how often they used various elements of their specialized training ranging from use of dissertation topic, the most specialized category, to use of general knowledge of science. Two additional categories used were use of computer and/or experimental knowledge (but not use of science knowledge) and, finally, “none of the above.”32 A useful summary of these results can be constructed by ordering the results in a hierarchy of specialization (see Table IV). For example, if respondents reported that they “often” used their dissertation topic, they were included only in that category and not as “often” using their specialty field. We found that relatively few (16%) Ph.D. physical scientists often use knowledge of their dissertation topic (Table IV). About one-third (32%) often used their Ph.D. specialty field, but did not often use knowledge of their dissertation topic. Another quarter (27%) often used knowledge of their general field (for example, physics, chemistry), but did not often use their more specialized knowledge. Slightly more than one in ten (13%) often used “general knowledge of science and/or how science works” while one in twenty (5%) often used computer and/or experimental skills—but did not often use the science knowledge from their Ph.D. training. Finally, there were some respondents (7%) who did not often use any of the above knowledge areas. The results in Table IV are broadly consistent with the AIP findings for Ph.D. physicists.38

The distribution of specialized knowledge use (Table IV) varies by employment sector. The most significant difference was between industry and the colleges/universities/research labs. Industry had the broadest distribution of knowledge use, with 36% often using their dissertation or specialty areas, 25% often using knowledge of their general field, 18% often using general knowledge of science, and the remainder split between the final two categories. A larger percentage of those employed in colleges/universities/research labs often used their dissertation topic or specialty field (60%), with universities and university-affiliated research labs employing the highest percentage of scientists (29%) who often used their dissertation topic. Note, however, that the use of spe-

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Table III. Amount of time spent on research and/or development (R&D) (including related activities: proposal preparation, writing reports/papers, etc.).

<table>
<thead>
<tr>
<th>Amount of time spent—Research &amp; development</th>
<th>None</th>
<th>Half</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>14%</td>
<td>17%</td>
<td>16%</td>
</tr>
<tr>
<td></td>
<td>19%</td>
<td></td>
<td>33%</td>
</tr>
</tbody>
</table>

Table IV. Use of knowledge areas, in order of “closeness to Ph.D. field,” showing the percentage who use the specified area “often.” Percentages in each category are exclusive of those above. The fourth category is “General knowledge of science/how science works” and the fifth category is use of computer and/or experimental skills.

<table>
<thead>
<tr>
<th>Knowledge area</th>
<th>% who use often</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dissertation</td>
<td>16%</td>
</tr>
<tr>
<td>Specialty</td>
<td>32%</td>
</tr>
<tr>
<td>General field</td>
<td>27%</td>
</tr>
<tr>
<td>General knowledge</td>
<td>13%</td>
</tr>
<tr>
<td>Computer/experimental</td>
<td>5%</td>
</tr>
<tr>
<td>None of above</td>
<td>7%</td>
</tr>
</tbody>
</table>
Table V. Respondents’ estimation of the quality of their graduate training (see the text) and the importance to their work of various skills. The five-point answer scale has been collapsed to three categories (Ref. 33).

<table>
<thead>
<tr>
<th>Skill</th>
<th>Quality-grad training</th>
<th>Importance to work</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>Med</td>
</tr>
<tr>
<td>Oral presentation</td>
<td>12%</td>
<td>26%</td>
</tr>
<tr>
<td>Writing reports/articles</td>
<td>18%</td>
<td>29%</td>
</tr>
<tr>
<td>Critical thinking</td>
<td>5%</td>
<td>17%</td>
</tr>
<tr>
<td>Analyzing data</td>
<td>7%</td>
<td>14%</td>
</tr>
<tr>
<td>Designing research projects</td>
<td>19%</td>
<td>32%</td>
</tr>
<tr>
<td>Work in interdisciplinary context</td>
<td>43%</td>
<td>25%</td>
</tr>
<tr>
<td>Grant writing</td>
<td>69%</td>
<td>18%</td>
</tr>
<tr>
<td>Management responsibilities</td>
<td>76%</td>
<td>16%</td>
</tr>
<tr>
<td>Financial management</td>
<td>90%</td>
<td>7%</td>
</tr>
<tr>
<td>Classroom teaching</td>
<td>33%</td>
<td>37%</td>
</tr>
</tbody>
</table>

Table VI. Percentage who ranked work activities important to work (answers of four or five on a five-point scale) by employment sector. Work activity categories not shown had relatively small variations (20%) in importance with respect to employment sector.

<table>
<thead>
<tr>
<th>Employment sector</th>
<th>Grant writing</th>
<th>Teaching</th>
<th>Management</th>
<th>Research design</th>
<th>Interdisciplinary work</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industry/business</td>
<td>13%</td>
<td>6%</td>
<td>71%</td>
<td>59%</td>
<td>77%</td>
</tr>
<tr>
<td>Four-year college or university</td>
<td>62%</td>
<td>75%</td>
<td>59%</td>
<td>73%</td>
<td>54%</td>
</tr>
<tr>
<td>University-affiliated research institute</td>
<td>60%</td>
<td>30%</td>
<td>72%</td>
<td>81%</td>
<td>70%</td>
</tr>
<tr>
<td>Government research lab</td>
<td>40%</td>
<td>6%</td>
<td>42%</td>
<td>71%</td>
<td>62%</td>
</tr>
</tbody>
</table>
ingly, the level of satisfaction with graduate training increases as the number of areas where high quality training was reported rises.

The second group of skills we identified consists of financial management, grant writing, and management generally. Only a relatively small proportion of graduates reported a high level of training in these skills (Table V). Training in grant writing is also correlated with writing reports and articles. Working in an interdisciplinary context is mildly correlated with research design, management, and critical thinking. The quality of training in teaching is not correlated with training in any of the other skills, indicating that teaching is a separate activity that is not well integrated into other aspects of either the formal or informal graduate curriculum.

Although it is not surprising that most graduates reported a low level of training in human and financial management (although a few did report high levels of such training), some of the other scores would seem to indicate problems with the graduate training system. One area that is often discussed is training for teaching. Only one-third of our sample reported a high level of training in classroom teaching. While most graduates do not teach in a classroom setting (Table V), the low ratings of training are striking because this is generally the only area in Table V that is likely to have a formal training component in graduate programs.

There has also been much discussion about the need for better interdisciplinary training, although quantitative evidence for such a training gap has been lacking. We found that only one-third reported that their graduate training for “working in an interdisciplinary context” was good (four or five). We found a significant gap between graduate training and work in this area given that 68% of our respondents replied that this was an important part of their work. We also found that only half reported a high level of training in “designing research projects.” This lack of good training for half of our sample is striking given that development of an independent research project is considered to be a core component of the Ph.D. degree. One possible explanation for this result could be that those who ranked their training low on this scale could have been students who worked on one of their advisor’s research projects and, therefore, had little chance to develop skills in project design. We do find that the 9% of our cohort who rated their self-direction during their thesis research in the lowest categories rated their training in “designing research projects” lower than average, with 36% giving a high rating to their training in this area.

Self-directed research projects are not the whole story, however, given that the majority of our respondents (59%) described their thesis research as being mostly self-directed. Only slightly more than half of these respondents ranked their training in “designing research projects” high. The result is that many graduates do not get good training in designing research projects, which is a commonly used skill in the workplace (Table V).

We found a correlation between the rating of graduate training and use of the skill in a job for most categories. This effect is strongest for the skills: “working in an interdisciplinary context” and “analyzing data.” For these two skills, 81% and 86%, respectively, of those who rated their training in these skills high reported that these two skills were important in their work. Of those who rated their training in these skills lower, 56% and 60%, respectively, reported that these skills were important in their work, a difference of 26% in each case. There is a small effect (on the order of 15% difference) for grant writing, designing research projects, and critical thinking. The effect is smaller still for oral presentation and writing reports/articles. Some of this correlation could represent differing interpretations of the questions by the respondents, in that specific definitions of each response category were not given. Another explanation might be that those with a high level of training in a particular area may also tend toward jobs that use that skill. The correlation between training and skill-use could also be due to a strong interest and/or aptitude for a particular skill, leading the respondent to seek out opportunities to use that particular skill. Of course, it may also be the case that a high level of training in a skill could be more likely to lead to success in using that skill in future jobs.

Overall, these data indicate the presence of gaps between graduate training and the skills needed in the workplace, as indicated in Table V. Only for the skills of analyzing data and classroom teaching are the training and work measures comparable. The contrast between these two measures is even larger than apparent in Table V because a smaller proportion rated their graduate training as “excellent” than the proportion who reported that this skill was “very important” in their work. These results are consistent with those of Golde and Dore, who also found gaps in the training needed for academic jobs in the areas of preparation for teaching and interdisciplinary research, but also on research management issues such as safety, appropriate use of funds, refereeing, publishing and authorship of papers. Austin also found “discrepancies between the preparation of the graduate students and the realities of both academic work and the academic labor market.” Our results demonstrate specific training gaps which are applicable not only for academics, but for physical science graduates, in general, regardless of their eventual workplace.

VII. THE INSTITUTIONAL CONTEXT OF GRADUATE TRAINING

If graduate training is to be improved, we should ask where, within the institutional context, this training takes place. Graduate students are mentored and trained by advisors, they are part of an academic department, enrolled in a university, and can also be considered part of an overall discipline which extends well beyond the department. We will explore the institutional context of graduate training by examining differences in respondent rankings of graduate training (Table V) at each of these levels.

We first examined differences by discipline. We used three categories: chemistry, physics, and other. Although a number of distinct disciplines fall into our “other” category, the numbers in each are too small to analyze separately. We found that the rated quality of graduate training varies systematically by discipline. Graduates from physics departments, overall, reported slightly lower levels of training (by 4%–14%) than graduates from chemistry departments in the areas of analysis, oral presentation, research design, working in an interdisciplinary environment, and grant writing (in decreasing order of difference). There were no statistically significant differences in terms of training between “other” physical scientists and physicists and chemists (taken altogether), although the fact that a number of smaller disciplines are included in the “other” category may eliminate any signal in these data.
We begin with the graduate advisor. Our interview data suggest that graduate advisors strongly influence graduates' training. Some respondents, for example, reported that advisors critiqued presentations and papers and sent them to conferences with directions to learn from good speakers. If the advisor had a significant effect on training outcomes, we would expect that rankings of graduate training would be more similar for students with the same advisor as compared to those with different advisors. We tested this hypothesis by comparing the training scores for two groups of students. The first group consisted of randomly selected pairs of students who did not have the same advisor and the second group that consisted of an identical number of student pairs who did have the same advisor. If ratings of graduate training are strongly influenced by the advisor, we would expect that the distribution of the training ranking differences for graduates with the same advisor would be shifted toward smaller values as compared to the distribution for students with different advisors. The results of this analysis are shown as a histogram in Fig. 1 for two of the training rankings. For training in research design, an area where we might expect a strong influence from the advisor, there is no consistent effect. Similar results are seen for the other training areas, except for teaching. The largest effect is seen for training in classroom teaching, where students with the same advisor tended to report more similar scores, although there may be a smaller effect for analysis and presentation skills. It is possible, however, that this correlation between training and advisor is an effect due to the subdiscipline of the student, where students in certain subdisciplines are more likely to be teaching assistants (due to a lack of research funding) and, therefore, receive greater training in teaching. We do not, therefore, see a strong influence of advisor on rankings of graduate training except for teaching.

We can also compare graduate training at the level of the department. Within our sample, 14 departments had a sufficient number of responses with which statistical tests (chi-squared) could be performed for one or more of the skill categories in Table V. Of the 96 resulting tests, only 9 showed a statistically significant difference, at the 10% level or better, in the reported level of graduate training in that department as compared to the discipline as a whole. Given the large number of tests, a few of these positive results would be expected by chance, although five of these results were significant at the 2% level or better. Of these nine significant differences, four were for training in “designing research projects.” The fact that several of the significant differences were for “designing research projects” provides some evidence that the level of training in this area could depend, in part, on the department. Three departments had a lower-than-average level of training in this area: with only 26%–41% of the respondents reporting a high level of training (as compared to 49% overall: Table V). One department showed a higher level of training, with 67% of their graduates reporting a high level of training in this area. Overall, however, graduate training does not vary strongly from department to department even though the overall reported level of training varies significantly by skill area (Table V).

With one exception, the differences in graduate training are scattered, in that a given department only deviates in one area from the average for that discipline. One department, however, was rated significantly below the average in three training areas, perhaps indicating some wider problem in this one department.

We, therefore, conclude that there is little difference between departments in graduate training variables. This conclusion is consistent with our finding above that overall graduate satisfaction does not vary significantly between departments. Note that no department had rankings of teaching training that were significantly different from the discipline as a whole. Nor were there differences between disciplines.

Moving one level higher, we also compared graduate training rankings at the university level by comparing scores for each university with the results for the rest of the sample. A few differences were found, although most were of marginal significance. A complicating factor here is that the differences seen above due to discipline will skew results for any given university if the distribution of respondents from that university is different from the average. As a rough test of this effect, results from each university were re-scaled so that the fraction of respondents from each discipline was identical. Although the resulting significance levels can only be taken as illustrative, only 2 results out of 67 tested were significant at the 10% level or better. We, therefore, find almost no training differences at the level of the university.

In summary, our data support moderate differences in training between disciplines, but only scattered differences between departments and limited differences due to the advisor. These results support previous suggestions that faculty have a greater affiliation with their discipline than with their
department, an affinity which would presumably extend to the research practices passed onto students.\textsuperscript{34,35} We, therefore, find little evidence that graduate training in the areas examined is strongly affected by the student’s university, department, or advisor, with the largest influence from the discipline.

**VIII. JOB SATISFACTION**

We now turn to job satisfaction, which is probably the most conclusive individual measure of the ultimate result of graduate education. About three-quarters (73%) of our sample responded with a positive level of satisfaction with their current jobs, with a quarter (24%) responding that they were “very satisfied;” 16% were neither satisfied nor dissatisfied, and 11% were dissatisfied (Table VII).\textsuperscript{36}

Note that 49% of the responses were in category 4. Although it is natural to label this response as “satisfied,” it should be kept in mind that, although these respondents did give a positive rating to their jobs, these ratings undoubtedly range from barely positive to quite satisfied but, evidently, not “very satisfied” (a similar comment applies to Table II). Satisfaction with specific aspects of the current job varied. Slightly less than half (47%) were satisfied, that is, response of four or five, with the amount of time spent “doing science,” while only 16% were “very satisfied.” Similar proportions were satisfied with their salary. A much more positive evaluation was given to the degree of self-direction experienced at work. Fully 50% reported that they were “very satisfied” with their level of self-direction at work and a further 31% responded with the intermediate positive rating.

The most important contributors to job satisfaction were identified through a series of logistic regressions. Logistic regression is defined as a nonlinear, non-normal regression that is based on a binomial distribution. Rather than a distribution of continuous values, outcomes are constrained to be either a value of 0 and 1, where a value of 1 represents an event occurring, and a value of 0 represents nonoccurrence.\textsuperscript{37} The advantages of logistic regression include its applicability for retrospective data, because it produces estimates of increases in probability based on chosen independent variables, and does not assume causality and time order of variables. The logistic regression also provides more reliable estimates when the data are categorical and not necessarily normally distributed, which is the case for the data here. We have also used clustering techniques for the estimation of standard errors of the logistic regression coefficients.\textsuperscript{38,39} It is likely that there are similarities between students within the same department that if not accounted for directly in our data, could result in an underestimation of variance if clustering is not used. In our logistic regressions, the job satisfaction variable was collapsed in one of two ways to form a categorical variable. The first test identifies if the respondent was satisfied (answers four or five) or not (answer categories 1–3). The second test identifies if the respondent was “very satisfied” (answer of 5) or not (answer categories 1–4).

Groups of variables from each section of our survey results were regressed against each of these logistic results and a final model incorporating statistically significant results from each group was tested.

The variables were further divided into two groups which we term “job characteristics” and “satisfaction/perception measures.” The first category consists of variables that are not direct measures of the perceptions of the respondent. This category contains characteristics of the job and personal history (although none of the latter measures were significant in these models). The second category consists of variables that directly measure the perceptions and attitudes of the respondent such as satisfaction with salary.\textsuperscript{40} The results of this analysis are shown in Table VIII. Variables are listed in rough relative order of importance, although the specifics can vary with employment sector and gender. The odds ratios associated with these results are shown along with the regression coefficient. The odds ratio represents the increased probability that a respondent reporting that indicator will experience the modeled outcome. For example, an odds ratio of 2.5 for intellectual challenge indicates that respondents reporting one unit higher level of intellectual challenge in their work are 2.5 times as likely to report being satisfied with their job.\textsuperscript{37}

Our results indicate that intellectual challenge, self-direction, job stability, and necessary resources are particularly important contributors to job satisfaction. A high level of daily job pressure is a negative influence on job satisfaction. Also of interest are the variables that do not influence job satisfaction. These include the amount of time spent on R&D, the employment sector, salary, tenure status (for academics), and use of specialized degree training.

Two variants of job satisfaction are considered in Table VIII. The first column indicates the variables that contribute to being satisfied in general, and the second column contains items that contribute to being “very satisfied” specifically. Although most of the variables predict both being “very satisfied” with the job and being satisfied in general (Table VIII), there are some differences. Respondents who reported that administering projects was part of their regular work activities were more likely to be satisfied with their jobs, although this job activity was not a predictor of being “very satisfied.”

Several variables had a statistically significant influence on being “very satisfied” with one’s job, but not job satisfaction in general. Work that will be of eventual benefit to society is a contributor to being “very satisfied” while enhanced data analysis skills since the Ph.D. is a negative influence.\textsuperscript{41} Chemists and physicists, as contrasted to “other” physical scientists, were also more likely to be “very satisfied” with their jobs, although this result has only a moderate level ($p<.05$) of statistical significance.

When the satisfaction/perception measures are considered (Table VIII) we find that satisfaction with the level of self-direction, salary, and time doing science all contribute to job satisfaction. The importance of job stability contributes to general satisfaction in that those who consider job stability important are more likely to be satisfied than those who rated job stability of intermediate or low importance. Again, independent of these variables, chemists and physicists were more likely to be “very satisfied” than “other” physical scientists.
### IX. DISCUSSION

Doctoral education has often been viewed as the epitome of specialized training, as the end point of an educational chain often described as a “pipeline.” Relatively recently, there have been calls for a broadening of graduate education in the sciences, to be more of a liberal education for a technical age. The National Academy of Sciences has recommended that graduate training should produce “scientists and engineers who are versatile” by allowing “students to gain a wider variety of academic and other career skills.” Career guides oriented toward scientists have emerged, one of which intends to show job seekers that a “wealth of opportunities exist for you in many career fields, especially because you have an advanced degree in science. Far from being a liability, a scientific training provides powerful problem-solving tools that are valuable in nearly every type of career.”

How useful is doctoral training in one’s later career? How does use of graduate training relate to job satisfaction? From an individual standpoint, job satisfaction is one of the most important outcomes to measure. The goal of the present project was to determine, qualitatively and quantitatively, the relationships between graduate training, satisfaction, and work of Ph.D. physical scientists in order to shed light on the extent that this work is also intellectually challenging. Work that involves R&D or use of their degree field does not appear to be intrinsically satisfying except to the extent that this work is also intellectually challenging. Causality for these relationships is difficult to discern. For example, it is not known if administering projects is an inherently satisfying activity, or if those who are good at their jobs, and perhaps are therefore more likely to enjoy them, are more likely to be in a position to administer projects. Overall, we find that the intrinsic characteristics of the job are the predictors of job satisfaction, not working “in one’s field.”

There is a large literature on job satisfaction. Factors identified as conducive to job satisfaction include: interesting work, appropriate and fair rewards, and adequate resources. Our results indicate that Ph.D. physical scientists are similar to others in these general respects. The satisfaction percentages (Table VII) found in our study are very similar to those found for federal employees in general, using a similar form for this question.

### Table VIII. Primary variables that contribute to job satisfaction as indicated through a logistic regression analysis (see the text). The first model distinguishes between those who are satisfied and those who are neutral or dissatisfied. The second model distinguishes between those who are very satisfied (answer scale = 5) and everyone else (scale: 1–4). The statistical results are presented as both coefficients and as odds ratios. Variables are presented in two groups, those that are job (or demographic) characteristics and those that are direct measures of the perceptions of the respondent (see the text). The contrast category for physics or chemistry Ph.D. is those who have a Ph.D. in “other” physical sciences.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Job characteristics model</th>
<th>Odds ratio</th>
<th>Coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intellectual challenge of work</td>
<td></td>
<td>2.5***</td>
<td>0.925***</td>
</tr>
<tr>
<td>Administers projects</td>
<td></td>
<td>2.3***</td>
<td>0.816***</td>
</tr>
<tr>
<td>Job stability</td>
<td></td>
<td>1.8***</td>
<td>0.571***</td>
</tr>
<tr>
<td>Availability of necessary resources</td>
<td></td>
<td>1.7***</td>
<td>0.558***</td>
</tr>
<tr>
<td>Level of self-direction on job</td>
<td></td>
<td>1.5**</td>
<td>0.576**</td>
</tr>
<tr>
<td>Daily job pressure</td>
<td></td>
<td>0.6**</td>
<td>-0.477**</td>
</tr>
<tr>
<td>Work will be of eventual societal benefit</td>
<td></td>
<td>1.3**</td>
<td>0.298**</td>
</tr>
<tr>
<td>Enhanced data analysis since Ph.D.</td>
<td></td>
<td>0.7**</td>
<td>-0.295**</td>
</tr>
<tr>
<td>Physics or chemistry Ph.D.</td>
<td></td>
<td>2.0*</td>
<td>0.675*</td>
</tr>
<tr>
<td>Satisfaction/perception measures model</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Satisfaction with level of self-direction</td>
<td></td>
<td>2.2***</td>
<td>0.807***</td>
</tr>
<tr>
<td>Satisfaction with salary</td>
<td></td>
<td>2.2***</td>
<td>0.779***</td>
</tr>
<tr>
<td>Satisfaction with amount of time doing</td>
<td></td>
<td>1.8***</td>
<td>0.590***</td>
</tr>
<tr>
<td>Importance of job stability</td>
<td></td>
<td>1.5***</td>
<td>0.386***</td>
</tr>
<tr>
<td>Physics or chemistry Ph.D.</td>
<td></td>
<td>1.8*</td>
<td>0.602*</td>
</tr>
</tbody>
</table>

*p<0.005.

**p<0.01.

***p<0.001.
and anecdotal data. We found that the use of the specialized disciplinary training varied quite widely (Table IV), with about half of the physical scientists in our sample often using their training in specialized knowledge areas while the other half of our cohort often used only more general knowledge areas. We found no evidence, however, that use of specialized graduate training had an effect on job satisfaction. For many graduates, a large portion of their graduate education—their focus on mastering a narrow specialty field—did not prove to be particularly useful in their later careers. The lack of use of specialty knowledge does not mean that graduate education is not useful, but instead of disciplinary knowledge, the most broadly used elements of a graduate education in the physical sciences are those that are only indirectly connected to disciplinary-based research activities. We found that most graduates often used a more general set of skills, including communication, research design, analysis, and management skills (Table V). Most graduates (88%) also use at least general knowledge of science or their general field (Table IV).

When graduates were asked to evaluate the quality of their graduate education, the results were decidedly mixed. Looking at a set of “core” research skills—writing reports/articles, oral presentation, analyzing data, designing research projects, and critical thinking—we found that about half reported a high level of training in four out of five of these areas. These skills are all rated as being important in the workplace by the majority of our respondents. Several additional skill areas stand out as having particularly large gaps between training and work. Our data clearly show a significant gap in interdisciplinary skills. The majority of our respondents reported that “working in an interdisciplinary context” is important in their work. This contrasts with 43% of our cohort who report that they received little or no training in this area, with only 32% reporting receiving a high level of training in this area. Even in the most traditionally academic activity, classroom teaching, only 30% of those for whom teaching is important to their work report having had a high level of training in teaching. Management activities stand out as an area that will be an important part of work life for most graduates, while only very few received significant training (including informal training) in this area.

This work supports the view that graduate training, at least as considered from the perspective of the work that Ph.D. scientists perform, should not be understood solely as a means of producing disciplinary specialists. Ph.D. scientists in the workplace can be more accurately described as workers who use a range of general analytical and communication skills, albeit with a substantial number who also use more specialized disciplinary knowledge. From a career perspective, we conclude that many Ph.D. scientists do, indeed, leave their graduate training with a set of valuable “problem-solving tools” that are useful in a variety of career tracks. About half of the graduates in our sample, however, reported that they did not obtain a high level of training in two or more core research skills. In addition, the majority were not prepared to work in an interdisciplinary context. Given that these skills are important in most work environments (Tables V and VI), we conclude that many of these graduates arrived on the job market ill equipped with important skills. Although some may make up for this lack by relying on use of their specialized disciplinary knowledge, clearly this is not the case for roughly half of our sample (Table IV) who reported not often using their most specialized knowledge.

Many of these graduates also lacked good training in more general research skills that are needed in the workplace.

Implementing improvements in graduate training, however, is likely to require significant changes in the culture of graduate education. Our finding that, for the most part, rankings of graduate training and graduate satisfaction do not vary significantly between departments supports previous suggestions that the academic culture has a disciplinary rather than institutional basis. We also found little evidence that the quality of training varies significantly by advisor. These findings would appear to indicate that current institutional structures generally have a limited influence on the quality of graduate training. The difference seen between chemists and physicists, however, could be due to some discipline-wide institutional influence, such as the undergraduate approval program of the American Chemical Society.

In summary, although the traditional academic focus is on disciplinary research, we found that the aspirations, careers, and work of Ph.D. physical scientists do not follow an academic stereotype. Graduate students appear to have a wide range of aspirations, although this range does not appear to be communicated to their fellow students. After graduation, we found the greatest commonality not in the use of disciplinary training, but in the use of general skills, with the work of Ph.D. physical scientists characterized by communication, analytic, critical thinking, and management skills, along with work in an interdisciplinary context. The attainment of the normative “academic position” is not a good predictor of job satisfaction four to eight years after the
Ph.D. Most important to job satisfaction are factors such as intellectual challenge and good working conditions. We found little support for such often-used dichotomies such as working “in” or “outside” of science (Tables III and IV). The attitudes of scientists and the work they perform lie on a continuum that defies simple characterization.

ACKNOWLEDGMENTS

The authors would like to thank Marc VanOverbeke, Emily Miller, Doug Wiese, Corinne McCuskey, Kerry Englert, and Andrea Pascarella for their work on this project. We would also like to thank the participating departments and universities and, most importantly, the scientists who participated in our interviews and returned our survey. The paper benefited from the comments of Sandra Laursen and Elaine Seymour and editing by Anne-Barrie Hunter. This project was funded by Grant No. SES-9704011 from the National Science Foundation with additional support from the NCAr Advanced Study Program.

1 Electronic mail: ssmith@mailaps.org
2 Electronic mail: pedersel@colorado.edu
5 Graduate Education and Postdoctoral Training in the Mathematical and Physical Sciences (Mathematical and Physical Science Directorate, National Science Foundation, Arlington, VA, 1985).
6 Characteristics of Doctoral Scientists and Engineers in the United States (National Science Foundation, 1997), NSF 97-308.
7 The 1997 SDR contained an additional question asking the extent to which the respondent’s doctoral education adequately prepared them for their career in a number of skill areas. These data have not yet been published.
8 Starting Salaries of Chemists and Chemical Engineers (American Chemical Society, Washington, DC, 1993).
10 D. Rosdil, What Are Masters Doing? (American Institute of Physics, College Park, MD, 1996), Pub R-389.1
11 About 200 of the respondents had obtained a Ph.D. degree and 328 had master’s degrees in some field (from Ref. 7).
13 These surveys were conducted by scientific societies and coordinated by the CPST (see www.cpst.org).
14 The sample was limited to those who resided in North America at the time of the survey. The eight universities included both public and private institutions. The major geographic regions of the US were represented.
15 For further project information and a copy of the survey see http://spot.colorado.edu/~phdcarer/.
16 The response rate for the mail portion of the survey was 55%. Most of the additional responses were to a phone version of the survey that omitted some questions. The response rate does not include 11% of the cohort who resided outside of North America and another 11% for whom we did not have a valid address. The survey reference date was October 10, 1998.
17 The boundaries between these categories are fluid. Respondents within the same institution sometimes placed themselves in different categories.
19 It is difficult to compare these figures directly, particularly because of our addition of “Government Research Laboratory” as a separate employer category. Several large laboratories that employ physical scientists are operated by universities and SDR respondents there may have chosen “university” as their employer. If half of the respondents in our government labs category were moved into our university category, the distributions would agree to within a few percent.
20 The generalizability of our results is also indicated by the similarity in skill use across sectors, that is, Table VI and accompanying text.
21 Quoted phrases represent direct quotes from the wording of either the question or answer scale. Descriptions not in quotes are paraphrased or inferred.
22 Only one of the nine departments in our study with a sufficient number of responses to test had a statistically significant difference in graduate satisfaction. We did find that “other” physical scientists, that is, not chemists or physicists, as a group had a higher level of satisfaction with their graduate experience, a result that was significant at the 5% level (chi-squared test).
23 Of the 8% who reported the highest level of pragmatic motivations for graduate school (obtaining a Ph.D. was a “pragmatic goal,” answer scale =5), one-third were dissatisfied with their graduate experience (p<0.1%; chi-squared). No other category on the pragmatic versus intrinsic scale, that is Table II, showed a statistically significant difference.
24 Removing those who reported the highest level of pragmatism, there was no difference in overall satisfaction with graduate school between those who had “definite” career goals at the beginning of their Ph.D. and others in the sample. Those with definite career goals, however, were somewhat more likely to be “very satisfied” with their graduate education.
25 M. Nerad, D. Gupta, and J. Cerny (private communication). For those fields with employment patterns closest to those of physical scientists, the data from Ref. 10 find that 65%, 53%, and 36% of graduates from biochemistry, computer science, and electrical engineering, respectively, reported academic aspirations at Ph.D. completion.
26 The overall stability of career goals with time in the data from Ref. 23 can best be tested by examining those individuals who had specific aspirations at Ph.D. start. Here there was only a slight decrease in the overall percentage who held academic aspirations at Ph.D. completion (76%) as compared to the start of the Ph.D. (81%). Some category crossing did occur, with individuals who initially had nonacademic goals changing to academic goals and vice versa. The largest change, however, was due to the 28% who initially had no specific goal (and, in this question format, therefore did not specify either an initial academic or nonacademic goal), most of whom developed some more specific goal by the time of Ph.D. graduation.
28 If our results for academic aspirations are divided into two categories, they split at 53% (= the sum of categories [5 + 4] + 0.5[3], see Table II).
30 When chemistry graduate students were asked about interest in faculty jobs with a three category scale (“not at all,” “possibly,” “definitely”), Golde and Dore found 31%, 49%, and 20%, respectively. For chemistry graduates, on our five-point scale (see Table II) we found: 25%, 22%, 13%, 24%, 15%, which appears to be consistent with the findings of Golde and Dore—given the difficulty of comparing disparate answer scales.
31 The full text was “A temporary position is defined as one that had an end date or fixed term at the time you were hired. This position includes post-docs, fellowships, visiting faculty, internships, etc. Please mark tenure track positions as permanent.” This approach is similar to that taken in the surveys of recent graduates in Ref. 11. Note that we did not use the term “post-doc” in our analysis. There is no standard operational definition of a “postdoctoral position,” particularly outside of academia, and some might consider this term pejorative. Our qualitative analysis indicated that the definition used here for “temporary position” would most accurately reflect the varied situations of the respondents.
32 Only half of those employed in four-year colleges or universities who were not on a tenure track reported a high (answer four or five) level of job stability as compared to 90% of those tenured or on the tenure track.
33 We did not see a difference between men and women in this percentage.
34 The “none of the above” category did not appear on the survey, but consists of those who did not report that they "often" used knowledge in any of the previous categories.
35 The quality of graduate training scale ranged from 1 = “None” to 5 = “Excellent.” The importance to work scale ranged from 1 = “Do not do” to 5 = “Very Important.” In Table V, responses of 1 and 2 = low, 3 = medium, and 4 and 5 = high.
The similarity with responses for the graduate satisfaction question (Table I) for the dissatisfied and "neither" categories is largely fortuitous. Most respondents did not answer the same way on both questions in these categories.

The parameters of a logistic regression model are estimated using the maximum-likelihood method, with estimates produced by an iterative algorithm. The coefficients produced by logistic regression analyses can be interpreted as the change in the log odds of the dependent variable associated with a one-unit change in the independent variable. To aid interpretation of the coefficients, we also present the inverse natural log of the coefficients, which results in estimates of odds rather than log odds. The odds ratio, therefore, tells us how a one-unit change in an independent variable increases (or decreases) the odds of the event occurring.


We note that all of these variables depend on perceptions, because our data are self-reports from respondents. As in any survey work, we implicitly assume that respondents, on average, can consistently report quantities such as "intellectual challenge." The second set of variables, however, are direct measures of respondent's perceptions and attitudes while the first set of variables can, at least in principle, be objectively measured.

The latter result can be interpreted as follows: those graduates who have done the most data analysis work since graduation are less satisfied with their jobs, all other factors being equal.


Note, that results for job satisfaction are very sensitive to the question wording (and perhaps survey mode), which can be seen by comparing the above results to the quite different pattern of responses in the General Social Survey, Ref. 46, and the National Longitudinal Surveys of Youth, Ref. 47.

47% of the general population report that they are "very satisfied" with their jobs. (Source: On-line data extraction, variable SATJOB, <http://www.icpsr.umich.edu>.)


Reshaping Graduate Education (National Academy Press, 1995).


Administered by the ACS Committee on Professional Training (CPT), <www.acs.org>.