RESEARCH TRAINING IN CHEMISTRY

S. WINSTEIN

University of California,
Los Angeles, Calif. 90024

Attending a meeting such as the present one is a rather new experience for me, since I am much more accustomed to participating in scientific meetings and reporting research results. However, I have been on the faculty of the University of California and training graduate students for more years than I care to admit, so I have necessarily been involved in university chemical education, the subject of this Symposium. I wish to thank the organizing committee for the invitation to participate in this symposium, and I might say that this new experience has so far not been unpleasant.

I have been asked to speak briefly at this session on research training (post B.S.). Perhaps research education would be a better term. If I had to summarize my feelings in one sentence, I would say that the way to receive a research education is to do research in the proper atmosphere. However, you probably expect me to elaborate on this somewhat, so I will try to outline the procedures and methods which, from personal experience, have been fairly successful in the training and guidance of graduate students in their thesis work and in the production of mature, independent investigators.

Since the participants in this Symposium represent a number of countries, various kinds of institutions and different fields of chemistry, I might point out that my experience has been gained in physical organic chemistry in America at a large institution which nowadays has some 200 graduate students in chemistry, some 50 to 60 postdoctoral fellows and some 40 faculty. Some of the procedures I will outline may not be applicable under other circumstances.

THE STUDENT

We might begin to define the man whose research education we are discussing, as well as his timetable. In general, he is a man with a B.S. degree after four years of undergraduate education at some other institution, a man who ranked well up in his graduating class. Over 75 per cent of these entering B.S. students have done a little undergraduate research. While a few of the entrants are predoctoral fellows with no teaching duties, most graduate students serve as teaching assistants for approximately two years, then become research assistants free of teaching duties. There is a light graduate course requirement which means that graduate students take some graduate courses for approximately one and a half or even two years. There is a cumulative examination requirement in the graduate student's major field so that the student takes a one-hour examination on an unannounced topic roughly

once a month (nine per year) until he has passed five (maximum 18 attempts permitted). Although the students tend to have little time for research for the first year or two, they are encouraged to become affiliated with a research group fairly early. Some of the best students do this almost immediately, but many students do not do so until after the first year. On the average, the graduate students at the U.C.L.A. obtain the Ph.D. degree after four and a half years, that is, some three and a half years after nominally commencing research or, to put it another way, after two and a half years of fairly concentrated research. Roughly half the students go into academic work and the rest into industry.

As to how the graduate student receives his research education, I am inclined to say that he receives it in research on his thesis problem and general reading, with considerable assistance from graduate courses and seminars. If one divides research education into research techniques and tools, on the one hand, and research thinking, on the other, the techniques and tools are learned largely on the thesis problem, while research thinking is learned on the thesis problem, as well as in graduate courses, seminars and reading.

THE RESEARCH GROUP

In connection with the research education of the student on his thesis problem, my whole research group is very important, so a few words of explanation on this are in order.

As my research teaching and research operation has evolved at the U.C.L.A., and I believe this experience is quite common in other institutions in America, at least in organic chemistry, my research group itself has contributed more and more to the research education of my graduate students. Specific ways the research group contributes to the education of the graduate student will be seen later. However, we might at the outset mention the composition and the operation of the research group.

In recent years, my individual research group has numbered about twenty people, usually about a dozen graduate students and eight postdoctoral fellows from far and wide. The postdoctoral fellows are interspersed in the laboratories among the graduate students, while the inexperienced beginning students are interspersed among the more experienced graduate students and postdoctoral people.

While large, expensive instruments, and service shops such as machine, electronic and glassblowing shops, and storerooms are owned and administered by the department, many smaller instruments and services are best handled at the individual research group level. To illustrate with my own research group, one member is responsible for preparing special purchase orders and routing them through our department business office. Two people are in charge of v.p.c. equipment. One man is in charge of thermostat rate baths and the Bureau of Standards and other special thermometers in the group. Another man is in charge of a special polarimeter. Still another has responsibility over the Beckman IR5A infra-red spectrophotometer. One person has the responsibility over the group files of samples and n.m.r., u.v. and i.r. spectra. Another is in charge of the isotope and special glassware cabinets. Still different people are in charge of the spinning band

column, photochemical equipment, hydrogenator, refractometer, t.l.c. equipment, and n.m.r. spinners, microcells, etc.

Our whole research group, professor, postdoctoral fellows and graduate students, has weekly meetings lasting two hours or even longer, on Wednesday afternoons. These meetings are distinct from the more general departmental seminars in that all the discussion concerns research going on in the group or related to it. Items discussed may be about a business matter, it may be about experimental difficulties in someone's work, it may be to take stock of the status of someone's problem and to consider what to do next, or it may be an item which has just appeared in the literature which is or could be related to some research going on in the group. Some of the items are those which have come up in private conversations during the week and have been suggested as suitable topics to bring up for discussion at the group meeting. Many of the items are brought up for the first time directly at the group meeting.

The group meetings tend to be quite extemporaneous, and a person may be called on to speak about his research problem on the spur of the moment, completely extemporaneously. On the other hand, people may volunteer to introduce some item for discussion either from personal research or from the literature. Depending on the situation, we might hear from as many as six people, or as few as one or two, during any particular group meeting.

The informal, extemporaneous, brain storming atmosphere at the group meetings tends to make them very helpful and profitable. They are usually quite stimulating and some of our good research ideas have first arisen at such group meetings.

CHOICE OF RESEARCH PROBLEM

One of the first steps in the research development of a graduate student is the choice of a thesis problem. This a very important step, for if a student is intrigued and excited by his thesis problem, he will tend to be more highly motivated and tend to develop better in his research than if his research problem seems dull to him. Thus, it is very important to try to match properly the student with the problem.

In America, the way a graduate student and a research director usually find each other and become affiliated helps considerably to match properly a graduate student with a problem. Thus, at the U.C.L.A., for example, an entering graduate student comes to the department, not to a particular professor. At the proper time, he interviews all the faculty in areas of possible research interest to him to learn what research is going on and what research problems are available. He is welcome to read pertinent reprints and preprints. He is also welcome to visit research group meetings. Then he chooses the research group in which he wishes to work. The fact that the student and research director find each other by mutual agreement is a factor favouring the proper match-up of student and research problem.

In choosing a problem for a graduate student, I try to avoid one which is too narrow. It should preferably give him a variety of experience. In my group I try to have the problems involve some synthesis, some measurements

and some calculation. However, these ingredients are mixed in different proportions in different problems, and it is worth trying to match the 'mix' with the temperament of the student as judged by his past performance and discussions with him. My tendency is to give the student a choice of several problems which I judge to be suitable for him and yet exciting and important.

A method I like to use in matching the student with a problem is to have him join the research group with the idea of working in a certain area, but without yet selecting a specific problem. The student can get set up in the laboratory and learn some of the pertinent techniques by working close to a mature graduate student or postdoctoral fellow working in the area. Then, after learning more about the subject and the techniques, a specific problem can be mutually chosen, taking into account the latest developments both in the group and elsewhere. Besides permitting the student to select the actual problem when he is more knowledgeable about the subject, this procedure provides that he chooses the problem when he is more nearly able to start making substantial progress on it, and thus be less liable to being 'scooped'. However, many students wish to choose the actual specific problem at the outset and, in these cases, it is more likely to become necessary to shift the problem somewhat by the time the student is making substantial progress, in view of developments disclosed in the literature.

LABORATORY TECHNIQUES AND TOOLS

If we follow a graduate student in his research development, we shall consider first the matter of research laboratory techniques, tools and lore.

As regards teaching laboratory techniques beyond those normally acquired in the undergraduate curriculum, some schools offer laboratory courses in research methods. However, there are mixed feelings about the desirability and success of such courses. We at the U.C.L.A. have essentially no courses specifically of this type. The nearest thing to such a course is an advanced synthesis course taken by some of the entering graduate students. We are great believers in having students learn techniques on an individual basis from someone, be he professor, postdoctoral, graduate student or departmental non-academic technician employee, who is already skilful in the particular technique.

In a research group of the size of mine, it is usually possible for a student to learn how to do any particular thing from some member of the group already expert at it. Usually, the two people find each other without my intervention. Occasionally, when the student is not yet fully acquainted with the whole group, I direct the student to consult another member of the group who I know is already expert in the technique or subject involved. Sometimes, but not very often, direct help on some particular technique is available only from some other research group.

To learn techniques and research methods, the students are encouraged to observe as much as possible the operations of their own laboratory mates, as well as those of others in the other laboratories of the group.

As the student develops laboratory knowhow and becomes one of the more experienced members of the research group, he generally graduates into one of the group job responsibilities which I outlined earlier. This gives him more

experience which stands him in good stead later when he is out on his own, running his own research laboratory.

It is worth commenting on the running of the very large departmental research instruments. At the U.C.L.A. and at many other institutions in America, the graduate students and postdoctoral fellows may be cleared to run the large departmental spectrographs. This, of course, is only after a good indoctrination and a demonstration of their competence to run the instrument. For example, a great many students are cleared to run the Varian A-60 n.m.r. spectrometers, fewer are cleared to run the HA-100 n.m.r. spectrometer, while fewer still are cleared to run the MS9 mass spectrometer. This procedure contributes to the research education of the student and makes it possible to do things research-wise on which the departmental technician in charge could not spend the time.

The computer has become a research tool in chemistry, and the students are encouraged to learn something about programming and the use of available programmes in their research. From time to time there are offered short computer courses which students who are interested may take. A member of the chemistry faculty is in overall charge of liaison with the computer centre, and a non-academic departmental employee is available to help people with their problems. In our group, for instance, we have programmes, which some of the members use, for treating rate data to obtain rate constants, $\Delta H^{\ddagger}$ and $\Delta S^{\ddagger}$ of activation, simulating n.m.r. spectra, simulating e.s.r. spectra, and various quantum-mechanical calculations. Again, it is usually possible for a new student to learn from a more mature graduate student or postdoctoral fellow how to use any particular programme.

RESEARCH THINKING

How to teach and develop research thinking ability in the student is harder to prescribe than how to learn techniques and tools. Even early in the student's research career, when I discuss with him from time to time what to do either in my office or in his laboratory, I try to have him suggest what he would do while I criticize and advise. I give him an early exposure at a group meeting so that the whole group is knowledgeable about the student's problem and can interact with him informally in the laboratories as well as at group meetings. From informal discussions in the laboratories and group meetings, the student learns that even the design of an experiment is worth serious thought and discussion. He learns how to think critically about research and how to decide what to do. As time goes on, the student develops judgement as to how much of an undertaking an outlined course of action really is. He learns to be alert to what occurs in the literature with a relation to his work.

Talking about research thinking more generally, the student learns, from interactions in the laboratories and from group meetings, the value of discussion and picking each other's brains. He senses more and more how ideas are generated in chemistry and how you get ideas in research.

In talking about the research education of the student, I have concentrated so far largely on the activities of my own research group. It is important to point out that another substantial part of a student's research education is

gained in the few graduate courses he takes for credit or audits and from the seminars or colloquia he attends. The graduate courses and seminars help define the research frontiers. They show how things were done and how matters were proved. Especially, the seminars illustrate the value of discussion and critical thinking and how ideas are generated. An example is a Thursday night Physical Organic Seminar at the U.C.L.A. with a tradition for active informal discussion. This is attended by nearly all the organic faculty and some from nearby institutions. The seminars commence at 7.30 p.m. and have been known to continue till midnight. The speaker may be interrupted for questions and discussion during his talk and informal discussion may continue after he has concluded. The atmosphere and personnel at the seminar are such that the seminars are very stimulating and instructive.

PROGRESS REPORTS

Another thing which contributes to a research education is the periodic research progress report. My general practice is to require these twice a year. These are to be written in the general style of a paper in the *Journal of the American Chemical Society* with Results, Discussion and Experimental Sections, or simply Discussion and Experimental Sections. The Experimental Section is expected to be somewhat more detailed than in a published paper. Properly reviewed by the research director and discussed with him, these progress reports are very helpful.

The progress reports represent an excellent discipline for the student in his actual research. It is when one is forced to marshal, organize, present and discuss one's results, that one thinks the hardest and attains the best perspective on what has been done, what is proved, what is missing, what should be done next. The review by the research director of the reasoning involved contributes to the student's research education.

Since most students in chemistry in America have had very little writing experience in their prior schooling, the research progress report is a good experience for them. A mature research man should be able to write a good report or a satisfactory paper on his work for publication. Towards this goal, the progress reports, reviewed for organization and style, represent an educational experience.

Early in the research career of the graduate student, when he is just beginning research and is still occupied with courses, examinations and perhaps assisting with teaching, his research progress is quite slow. Therefore, his initial progress report may contain his statement of the problem and very few results, with the presentation leaving much to be desired. Later in the research career, much greater progress is made, and the reports become more substantial. Invariably, definite, consistent and gratifying improvement in the presentation can be seen in succeeding progress reports. Substantial portions of the progress reports, especially experimental portions, are useful later in the preparation of the thesis.

While on the subject of writing, I might mention another related educational experience I try to arrange for my students. This is in the preparation, wherever possible, of the first draft of a paper or communication for publication based on their work while they are still around. The preparation of

this first draft and then the polishing of this manuscript by both of us jointly is, in my opinion, an educational experience.

This concludes my attempt to be explicit about the procedures and methods which I have used at the U.C.L.A. in the research education of the student. The resulting products after four years or more proceeding through the whole educational process are respectably competent, mature and independent investigators. This probably proves only that, if you select the students properly with the right genes and let them do research in a stimulating research environment, they will nearly inevitably develop favourably.

I have concentrated on the graduate student being educated for the Ph.D. degree. While I have mentioned postdoctoral fellows in my research group, and these postdoctorals certainly contribute to the education of the graduate student, I haven't mentioned postdoctoral education. The latter is nowadays a legitimate field of education, and it is quite common to have a year or two of postdoctoral work at an institution different from the one where graduate work was done, especially prior to undertaking an academic career. While the postdoctorals help teach the graduate students in a research group, they also may learn from them. The year or two of research in a new research group and the exposure to the graduate courses, seminars and atmosphere of the new institution certainly allow the postdoctoral to mature further and develop ideas before commencing his own academic career.

DISCUSSION

R. S. Nyholm (*University College, London, U.K.*)—What method of assessment do you prefer for deciding whether a student is worthy of a Ph.D.? In particular, have you any comparisons between the methods used at the U.C.L.A., a small U.S. university and the average U.K. university?

J. F. Bunnett (*University of California, Santa Cruz*)—Ph.D. theses are commonly examined in U.S. departments by a committee of professors. If the thesis has been presented in a final, formally typed form, the making of major changes is a traumatic experience, expensive, time-consuming and humiliating. Therefore, many American departments now use a system in which theses are first examined in draft form by a committee of professors, so that changes can be made before the final typing.

A. D. Walsh (*University of Dundee, U.K.*) (written contribution)—The complaint has been made that our Ph.D.s are far too highly specialized. The point I wish to make is that whether or not this statement is true, it is much less true in Scotland than elsewhere. For the Scottish educational scheme is very broadly based indeed. Thus at the University of Dundee, a student in his first university year takes three subjects equally. In his second year, he takes two subjects equally; and then (for an honours degree in chemistry) spends two years devoted to the study of chemistry alone. The honours course thus lasts a total of four years. In the last term of the final year, no formal teaching is given. Specialization is only allowed (and then to a very limited extent) in the middle term of the final year; and thus only enters in one term out of twelve. It takes the form of allowing students to choose, say, five courses out of some sixteen offered. The latter comprise ten lectures and include such titles as spectroscopy, quantum mechanics, thermodynamics,

radiation chemistry, polymer chemistry, organometallic compounds, transition metal chemistry, carbohydrates etc.

These short courses have a second use; they provide course work for our research students, each of whom has to attend each year at least one course that he has not attended previously.

Research work, of course, demands intense preoccupation with a specialized problem; but at least the need for that specialized concentration is superimposed in Scotland upon a very broad background.

Incidentally, the short courses have one other function; they are suitable as refresher courses for those in industry or school teaching.