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# Vocational training for medicinal chemists: views from industry

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**Summary** — The Medicinal Chemistry Section of IUPAC sent a questionnaire regarding academic training for medicinal chemists to major research pharmaceutical companies in various countries in July 1992 and again in July 1993. A total of 102 replies were received from 65 companies, mainly from Germany, Italy, Japan, the UK and the USA, and these have been analysed and the results are presented. Most companies (> 90%) indicated that they seek to hire organic chemists who may have received some additional education in medicinal chemistry, rather than hire specialists in medicinal chemistry. The subjects most often mentioned as being desirable for the additional education were biochemistry (or drug metabolism and pharmacokinetics), pharmacology and physiology, computer modelling and QSAR, and molecular biology.

**postgraduate / curriculum / education / teaching / training / vocation / industry**

## Introduction

The education of medicinal chemists has been under discussion by the Medicinal Chemistry Section Committee [1] of IUPAC (International Union of Pure and Applied Chemistry). One result has been to set up a Working Party to consider a medicinal chemistry curriculum. It was decided to seek the viewpoint from an industrial perspective of what academic training (if any) should be provided in medicinal chemistry. A questionnaire was devised [3] and was sent in July 1992 to research directors or directors of medicinal chemistry in major research pharmaceutical companies in Western Europe, Japan [4] and the USA, inviting them to complete the questionnaire and return it (to WDB).

Replies were received from approximately 43 companies, the greatest numbers of which were in Germany, Japan and the UK. The companies were also invited to photocopy the questionnaire and distribute it to their senior medicinal chemists in research. A total of 67 replies were received and these provided an initial set of data which was analysed [5] and reported in a conference proceedings [6].

Initially there were insufficient replies from certain countries, and therefore the questionnaire was again sent in July 1993 to companies in France [7], Italy [7] and the USA [8]. The American companies returned a total of 33 replies and these data have been published separately [9]. The Italian replies were presented at the 11th National Convention of Italian medicinal chemists, Bari, 1994 [10]. There were also returns from other countries but the numbers (in parentheses) were too few for analysis, thus: Belgium (1), France (1), Switzerland (2), Sweden (1) and unattributed (2).

The results have engendered considerable interest among medicinal chemists and therefore the data from the main countries responding (a total of 95 replies) are presented in this article to permit a wider comparison of the responses, according to country.

## What is medicinal chemistry?

In the present context of the pharmaceutical industry 'medicinal chemistry' is the design and synthesis of compounds for biological evaluation as potential new drug therapies, ie, the generation of new chemical entities (NCEs) for medicinal purposes. In the pharmaceutical industry this is within the discovery phase of research and development (R&D).

A more comprehensive definition formulated by the IUPAC Medicinal Chemistry Section [11] is that "Medicinal chemistry is a chemistry-based discipline, also involving aspects of biological, medical and pharmaceutical sciences. It is concerned with the

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invention, discovery, design, identification and preparation of biologically active compounds, the interpretation of their mode of interaction at the molecular level, the construction of their structure–activity relationships, and the study of their metabolism."

## Why have vocational training in medicinal chemistry?

The pharmaceutical industry is the major employer of organic chemists engaged in research and development of new chemical entities for therapeutic purposes. Many prospective chemist employees are recruited to become industrial medicinal chemists without having had previous training in medicinal chemistry or exposure to biology. They are expected to fit into a multidisciplinary team of scientists searching for novel molecules with the intention to produce new medicines and to acquire most of their expertise on the job. When it comes to hiring such chemists the pharmaceutical employer generally seeks the brightest and most dynamic synthetic organic chemists, most often with a PhD and postdoctoral experience in the laboratory of well-known and highly regarded professors of organic chemistry.

The newly appointed chemists have to synthesize new molecules suitable for specific biological testing aimed at human or animal application. This usually makes full demands on their synthetic skills but will certainly not provide research medicinal chemists with a fully rewarding intellectual experience unless they also have an appreciation of the reasons for making the compounds. Furthermore, companies expect chemists to understand the research they are engaged in and to appreciate the eventual human or animal use. They must learn to interact with diverse biological scientists, for example, with biochemists, pharmacologists, toxicologists, molecular biologists, and formulation scientists in order to be actively involved in drug design. They will increasingly want to decide what compounds to make, as well as identifying how to make them. Explosive increases in knowledge in collateral fields such as pathophysiology, cell biology and genetics must be assimilated at the same time.

The novice medicinal chemist will also come up against the mystery of trying to relate chemical structure to biological activity in the face of insufficient data. In this connection colleagues will mention the importance of lipophilicity, hydrophobic interactions, quantitative structure–activity relationships (QSAR), principal component analysis, electrostatic energy potentials, agonists and partial agonists, etc. These are often unfamiliar words and new concepts that will be difficult to acquire and which take time to comprehend and use appropriately. Very few organic chemists will have taken courses in drug design during their university training. Some may have taken courses in natural product chemistry or bioorganic chemistry but these topics will be of comparatively little help in tackling structure–activity analysis. Their situation in the 1990s is rendered even more difficult since the extensive mentoring, which was a feature of previous times, is being eroded by company mergers and the resulting enforced early retirements of experienced practitioners.

One may well ask, therefore, whether such chemists have had adequate university training and whether it would be preferable if they had already received more exposure to medicinal chemistry concepts while at university. On the other hand, there are schools of pharmacy which have departments of medicinal chemistry; although primarily helping to train pharmacists, many also train research medicinal chemists.

This question of the most appropriate form of education for medicinal chemists is international in scope. In Germany and the UK the pharmaceutical companies generally hire organic chemists rather than chemists who have been trained in schools of pharmacy. In Italy every university has a pharmacy faculty and students can opt for a research doctorate in 'chemistry and pharmaceutical technologies' (the Italian 'CTF' which was introduced nationally in 1980 to prepare graduates for entry to drug research in the pharmaceutical industry or in academia) yet still companies appear to prefer to take on organic chemists (see below). In Japan the situation is somewhat different since the majority of medicinal chemists in the pharmaceutical industry have graduated from faculties or departments of pharmaceutical science or science, agriculture, or engineering where they have also specialised in organic chemistry. It is common for pharmaceutical companies to hire medicinal chemists with a Master's degree who have studied courses in pharmaceutical science at university; some have obtained a PhD in addition and quite a number of chemists take a PhD whilst working at the company (information from Dr J Ide, Sankyo Co). Thus, the situation for the training of medicinal chemists is different in Japan since they have generally studied biologically based subjects before graduating. In the USA there are departments of medicinal chemistry in universities that not only train pharmacists but also grant research degrees in medicinal chemistry.

## Questionnaire sent to companies

The problem of suitable training touches all involved in medicinal chemical research. Thus it seemed to be highly appropriate for the working party to start by

determining the attitudes of the pharmaceutical companies as the 'customer' for the university 'product' of trained chemists. Hence, as indicated in the *Introduction*, a questionnaire was sent out. Because the replies were somewhat startling and provocative and appear to cross national boundaries it is of interest to share the results with the international community of active medicinal chemists and educators. Medicinal chemists, like other chemists, may take up various jobs, but it is clear from the questionnaire replies that the industrial chemists focused their attention on the design and synthesis of new compounds for biological testing. No doubt, this was assisted by the preamble of the questionnaire which stated: "Medicinal chemists involved in new drug discovery have to be outstandingly good in synthetic organic chemistry and to understand modern approaches to structure–activity analysis. In addition they need to appreciate important concepts at the interfaces with many other scientific disciplines involved in the drug design process. In the past, most medicinal chemists were organic chemists who had to acquire the language and concepts needed to become medicinal chemists 'on the job'. This takes a long time, however, and, as is well known, not all organic chemists make a good transition. It should be possible to greatly accelerate the learning process by introducing appropriate training either whilst chemists are still at university or shortly afterwards. We would value your opinion on this issue."

Several answers indicated that there was no need for medicinal chemistry to be taught in universities, because the subject could be taught adequately within the company. On the other hand, this was more than counterbalanced by the replies that wanted organic chemists foremost but also preferred them to have an awareness of biologically based subjects such as biochemistry, pharmacology, physiology and molecular biology.

## Results from analysis of the answers to the questionnaire

The questionnaire was comprised of seven main questions plus a request for information about the respondent (position, responsibility, training and involvement in drug discovery). The numbers of companies polled and responding per country are given in table I.

In order to render the data between countries more readily comparable the responses are given as percentages rather than as absolute numbers. The latter can, however, be easily derived from the indicated total numbers of responses. Because the total numbers of replies per country differ markedly, the minimum percentage responses also differ substantially. Thus, for Italy the minimum response (1 out of 9 possible) appears as 11%, whereas for Japan (1 out of 23 possible) it is 4%, and for the USA (1 out of 33 possible) it is 3%.

*Question 1: When recruiting a new medicinal chemist, what do you look for in terms of knowledge, expertise, qualification?*

This is an open question and no guidance was provided as to how to answer. Some misunderstanding was apparent from the answers in differentiating between knowledge, expertise, and qualification. These terms were not defined in the questionnaire since it was assumed that their meanings were self-evident. Some of the replies reflect the different national educational cultures and systems. Thus experimental skills may be taken for granted when considering a PhD or postdoctoral appointment but would be important for a graduate; this probably accounts for the high rating given in the UK, where quite a number of graduates (BS equivalent) are hired.

A large majority of answers indicated (table II) that they were seeking chemists with advanced knowledge in organic chemistry (over 80%) and expertise in organic synthesis. Indeed, over half of the replies from Germany and the USA suggested that they required a PhD with postdoctoral experience in synthetic organic chemistry. Among the additional knowledge and qualification required, biochemistry figured quite highly, and pharmacology and molecular biology had some mention. Surprisingly few answers mentioned molecular modelling or experience in computing.

**Table I.** Numbers of companies asked and responding per country.

| | *Germany* | *Italy* | *Japan* | *UK* | *USA* | *Total* |
|---|---|---|---|---|---|---|
| No of companies asked | 12 | 16 | 44 | 14 | 33 | 119 |
| No of companies replying | 10 | 7 | 12 | 12 | 18 | 59 |
| Total number of replies[a] | 12 | 9 | 23 | 18 | 33 | 95 |

[a]The number of replies is greater than the number of companies because the latter were invited to make more than one return (see *Introduction*).

**Table II.** Answers to Question 1 per country expressed as percentages: *When recruiting a new medicinal chemist, what do you look for in terms of knowledge, expertise, qualification?*

| | *Germany* | *Italy* | *Japan* | *UK* | *USA* |
|---|---|---|---|---|---|
| *Knowledge* | | | | | |
| Organic chemistry | 83 | 78 | 48 | 100 | 88 |
| Biochemistry | 17 | 22 | 17 | 11 | 27 |
| Pharmacology | 17 | 11 | 17[a] | 0 | 6 |
| Molecular biology | 8 | 0 | 9 | 0 | 3 |
| Computer modelling | 0 | 22 | 9 | 6 | 0 |
| Physical organic chemistry | 0 | 11 | 0 | 22 | 15 |
| Medicinal chemistry | 8 | 0 | 0 | 6 | 12 |
| *Expertise* | | | | | |
| Synthetic organic chemisty | 58 | 56 | 57 | 83 | 61 |
| Experimental skills | 8 | 0 | 9 | 83 | 6 |
| Computer experience | 8 | 0 | 17 | 6 | 3 |
| Biochemistry | 17 | 0 | 0 | 0 | 0 |
| Pharmacology or biology | 17 | 0 | 0 | 0 | 9 |
| *Qualification* | | | | | |
| Postdoctoral | 58 | 11 | 9 | 29 | 55[b] |
| PhD | 42 | 56 | 43 | 88 | 6 |
| MS (or Laurea) | | 33 | 43 | | |
| Graduate | | | 13 | 71 | |

[a]13% indicated biology; [b]in many cases this was seen as an advantage but not as a determinant.

*Question 2: Do you prefer to employ A: specialists in medicinal chemistry who have acquired expertise in synthetic organic chemistry, or B: organic chemists with additional education in medicinal chemistry?*

A very high percentage (> 90%) gave their answer as 'B' (table III). Many of the answers indicated very strongly that the basic education must be in synthetic organic chemistry since medicinal chemistry can be acquired later whereas it is extremely difficult to do the reverse, ie, to learn a high level of expertise in organic synthesis after leaving university training. Indeed, several answers indicated that there was no need for medicinal chemistry to be taught in universities, because the subject could be taught adequately within the company. On the other hand, this was more than counterbalanced by the replies that wanted organic chemists foremost but also preferred them to have an awareness of biologically based subjects such as biochemistry, pharmacology, physiology and molecular biology. It would have been interesting to see the response to a third category C: organic chemists who have received no education in medicinal chemistry or other biologically based subjects, but this was not requested.

*Question 3: If you were to employ a synthetic organic chemist who will join your company to become a medicinal chemist, please indicate your priorities for additional education against the listed subject disciplines, and indicate the stage at which each subject should be acquired*

The number of responses to each subject is shown for the respective priorities and stages for teaching. The data for the returns from each country are shown sepa-

**Table III.** Answers to Question 2 per country: *Do you prefer to employ: A specialists in medicinal chemistry who have acquired expertise in synthetic organic chemistry, or B organic chemists with additional education in medicinal chemistry?*

| | *Germany* | *Italy* | *Japan* | *UK* | *USA* |
|---|---|---|---|---|---|
| Answer A | 1 (8%) | 1[a] (11%) | 1 (4%) | 1 (6%) | 1 (3%) |
| Answer B | 11 (92%) | 9 (100%) | 21 (91%) | 17[b] (94%) | 30 (91%) |
| No answer or no preference | 0 | 0 | 1 (4%) | 0 | 2 (6%) |

[a]One reply indicated that a mixture of A and B is required to provide a good balance; [b]two replies indicated that they prefer organic chemists per se (ie, *without* additional education in medicinal chemistry).

rately in the *Appendix* (table IX). The priorities for each subject have also been given a total score which represents the sums of the number of answers times the priority value. The total score is also presented as a percentage of the maximum possible. These percentages are collected together in table IV to allow comparison between the different countries. Biochemistry was not mentioned among the subjects listed but was broken down into *biological chemistry* (which was identified as encompassing enzyme mechanisms, nucleotides, proteins and peptides, carbohydrates, membranes), *drug metabolism* and *pharmacokinetics*. The results are also shown graphically in figures 1 and 2.

For many subjects there is quite a wide diversity of opinion as to priority rating and stage for learning, however, almost all replies identified synthetic methodology (97%) and a mechanistic approach to synthetic chemistry (93%) as having priorities (ratings 4 and 5) for additional education especially at the graduate stage. High priority (3–5) was also given to biological chemistry (at all stages), physical organic chemistry (undergraduate and graduate) and to a general knowledge of drugs and drug action. Biological subjects, such as molecular biology, pharmacology and bioassay had medium to low priorities as did drug metabolism and pharmacokinetics (mainly stage d). Computational modelling and QSAR theories and correlation analysis had medium priorities (rated 3–4 at all postgraduate stages). Specialist topics like analytical chemistry, process development and pharmaceutical technology received a medium to low rating (2–3). Specialist biological subjects like physiology and toxicology had low priorities (rated 1–3), and microbiology was rated even lower (1–2).

Some marked differences by country were apparent in the suggested stages for learning various subjects. Thus the Japanese preferred that microbiology and toxicology should be taught to undergraduates and that metabolism, pharmacokinetics, knowledge of drug action, and molecular biology should be taught to graduate students. In contrast the British and American responses preferred on the whole that these subjects should only be tackled when in industry. This doubtless reflects the national differences in the educational process. In Japan, the undergraduates are taught from faculties of pharmacy whereas in the UK and the US the preference is that undergraduates and graduate students are taught undiluted chemistry.

*Question 4: If additional courses in medicinal chemistry were to be offered as options to chemistry students, what should be their contents?*

This is an open question. The possible courses were not identified in the question but they were mentioned already in Question 3. The question also does not differentiate between undergraduate or graduate students. Answers are listed in table V. Subjects cited by a substantial proportion of respondents are molecular

**Table IV.** Answers to Question 3 per country expressed as percentages of total possible scores per subject (see *Appendix* for scores): *If you were to employ a synthetic organic chemist who will join your company to become a medicinal chemist, state your priorities for additional education against the listed subjects (rated according to priority where 1 is low and 5 is high priority).*

| | *Germany* | *Italy* | *Japan* | *UK* | *USA* |
|---|---|---|---|---|---|
| No of replies to Q3 | 11 | 9 | 22 | 18 | 30 |
| Synthetic methodology | 100 | 89 | 84 | 100 | 97 |
| Mechanistic synthesis | 82 | 76 | 75 | 97 | 88 |
| Physical organic chemistry | 47 | 56 | 58 | 78 | 71 |
| Biological chemistry | 73 | 49 | 78 | 72 | 71 |
| QSAR | 47 | 62 | 75 | 69 | 65 |
| Computational modelling | 71 | 64 | 70 | 66 | 65 |
| Analytical chemistry | 44 | 58 | 55 | 38 | 47 |
| Process chemistry | 31 | 53 | 54 | 32 | 52 |
| General knowledge of drug action | 71 | 58 | 76 | 73 | 72 |
| Drug metabolism | 58 | 49 | 72 | 68 | 58 |
| Pharmacokinetics | 49 | 38 | 69 | 66 | 56 |
| Prodrugs | 53 | 51 | 59 | 49 | 54 |
| Principles of pharmacology | 62 | 51 | 61 | 71 | 63 |
| Physiology | 53 | 31 | 63 | 51 | 45 |
| Molecular biology | 80 | 53 | 58 | 67 | 57 |
| Toxicology | 49 | 29 | 56 | 47 | 45 |
| Microbiology | 47 | 29 | 51 | 43 | 37 |
| Pharmaceutics | 36 | 31 | 44 | 33 | 38 |

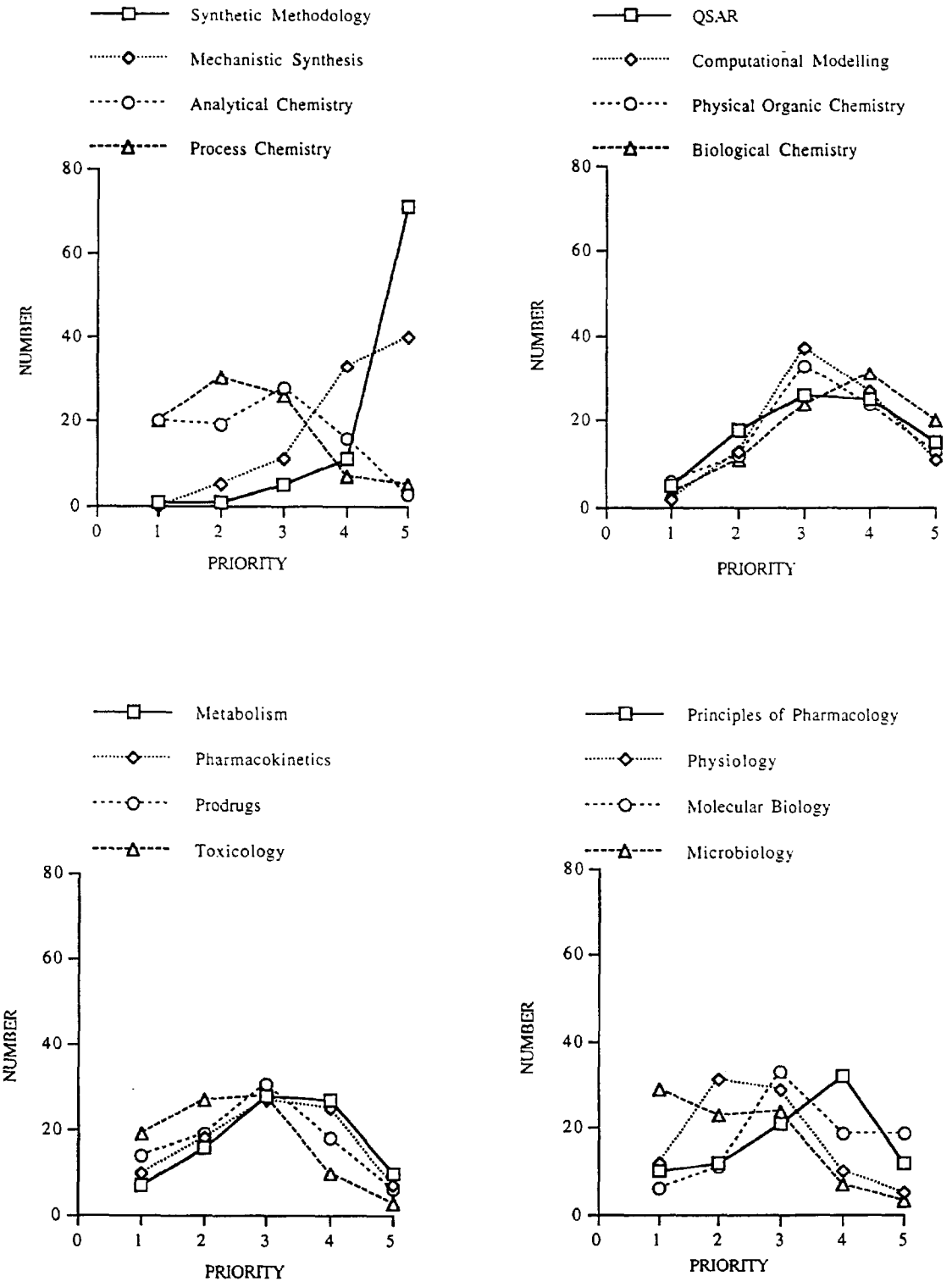


**Fig 1.** Priorities for additional education: total number of responses to Question 3 for each subject plotted against priority rating. Data in *Appendix* (table IX).

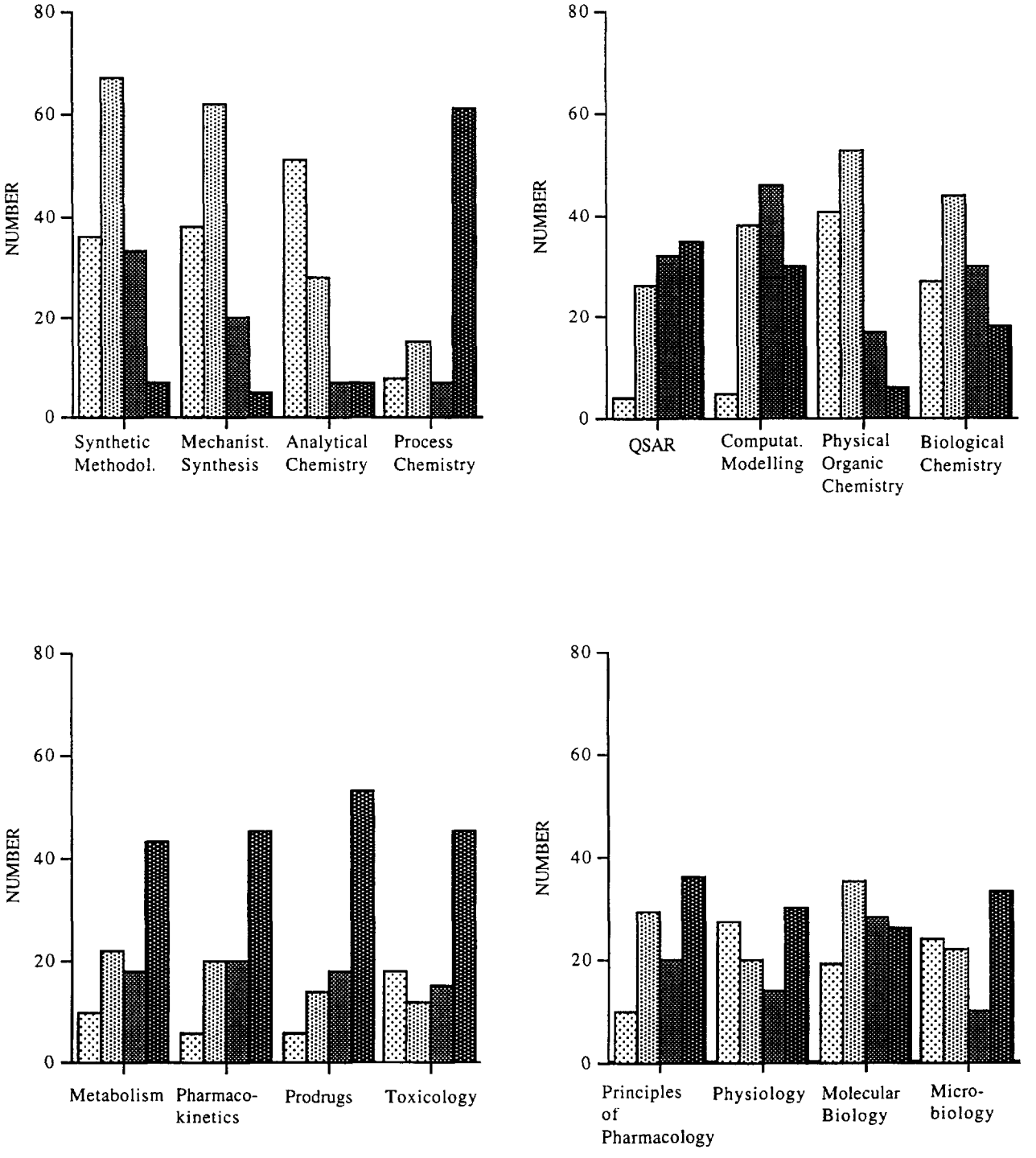


**Fig 2.** Stages when subjects should be taught: total number of responses to Question 3 for each subject plotted against stage. Data in *Appendix* (table IX). Undergraduate; graduate student; postdoctoral appointment, only in industry.

**Table V.** Answers to Question 4 per country: *If additional courses in medicinal chemistry would be offered as options to chemistry students, what should be their contents?*

| *Subject* | *Percentage number of responses* | | | | |
|---|---|---|---|---|---|
| | *Germany* | *Italy* | *Japan* | *UK* | *USA* |
| Modelling or QSAR | 50 | 33 | 35 | 40 | 36 |
| Pharmacology or physiology | 58 | 33 | 22 | 40 | 33 |
| Molecular biology | 25 | 11 | 26 | 27 | 30 |
| Enzymology | 17 | 0 | 9 | 33 | 24 |
| Biochemistry or DMPK[a] | 17 | 22 | 13 | 40 | 21 |
| Drug design | 0 | 0 | 9 | 0 | 18 |
| Case histories of drug discovery | 0 | 0 | 0 | 33 | 6 |
| Drug action | 0 | 22 | 9 | 40 | 9 |
| Biological chemistry | 17 | 11 | 9 | 7 | 9 |
| Toxicology | 25 | 0 | 0 | 0 | 3 |
| Microbiology | 8 | 11 | 4 | 0 | 3 |
| Cell biology | 0 | 0 | 13 | 13 | 0 |
| No answer | | 33 | [b] | [c] | 6 |

[a]DMPK = drug metabolism and pharmacokinetics; [b]other subjects mentioned were statistics, use of the biological literature, protein chemistry; [c]four respondents (22%) indicated that medicinal chemistry courses should *not* be offered.

modelling or QSAR (33–50%), pharmacology or physiology (22–58%), molecular biology (25–30%), biochemistry or drug metabolism and pharmacokinetics (13–44%) and enzymology (9–33%).

*Question 5: Should universities provide specific courses for medicinal chemists already employed in industry? If yes, please list topics in your priority order*

This is another question in which the possible subject courses were not identified, but they had, of course, already been mentioned in Question 3. The question does not identify how the courses should be organized, eg, for a short period (1 or 2 weeks), full time, or as a series of evening lectures. Answers are listed in table VI. It is noteworthy, and rather surprising, that 13–20% of respondents in Japan, UK and USA felt that such curricula should not be offered at all! Except for Japan, subjects cited by a substantial proportion of respondents are pharmacology or physiology (33–67%), QSAR or molecular modelling (27–50%), molecular biology (25–30%), biochemistry or drug metabolism and pharmacokinetics (30–44%).

*Question 6: Please list your suggestions for a medicinal chemistry curriculum*

This was not posed as a question, and nothing was specified as to when a medicinal chemistry curriculum

**Table VI.** Answers to Question 5 per country: *Should universities provide specific courses for medicinal chemists employed in industry? If yes, please list topics.*

| *Subject* | *Percentage number of responses* | | | | |
|---|---|---|---|---|---|
| | *Germany* | *Italy* | *Japan* | *UK* | *USA* |
| Pharmacology or physiology | 42 | 44 | 13 | 33 | 39 |
| Biochemistry or DMPK[a] | 42 | 44 | 13 | 40 | 30 |
| Modelling or QSAR | 50 | 33 | 30 | 27 | 30 |
| Molecular biology | 25 | 0 | 13 | 27 | 30 |
| Drug design | 0 | 0 | 0 | 7 | 18 |
| Enzymology | 8 | 0 | 0 | 13 | 12 |
| Toxicology | 42 | 11 | 4 | 7 | 6 |
| Biological chemistry | 8 | 33 | 13 | 7 | 6 |
| Organic synthesis | 0 | 0 | 13 | 13 | 3 |
| Should not be offered | 0 | 0 | 17 | 13 | 20 |
| No answer | 0 | 11 | 26 | 17 | 15 |

[a]DMPK = drug metabolism and pharmacokinetics.

should be taught. It is presumed that the respondents were giving their views as to what subjects in general constitute the knowledge base for medicinal chemistry. Answers are listed in table VII. No single subject is mentioned by more than 40% of respondents. Apart from Japan, the most popular subjects were biochemistry or pharmacokinetics and drug metabolism (17–40%), pharmacology or physiology (17–40%), synthetic organic chemistry (17–56%, but not from the UK) and molecular modelling or QSAR (7–21%). This last response rating is surprisingly low given that molecular modelling or QSAR received substantially higher ratings in answers to Questions 3–5.

*Question 7: Having regard to the present recruitment situation in your country, what suggestions do you have for the future to better train chemists in medicinal chemistry?*

Various suggestions were made in answer to this question and a representative selection is listed below. Some of the answers reflect the national character of the university training and so they are grouped by country. Some of the views expressed are distinctly contradictory.

Germany: 'Medicinal chemistry courses should be offered to graduate students in chemistry.' 'Require stronger co-operation between industry and universities.' 'Encourage postdoctoral study abroad in an excellent laboratory.'

Italy: 'Italy has courses for chemistry and chemistry with pharmaceutical technologies (CTF) but none gives the right training for medicinal chemistry; they should be mutually reorganised.' 'It is not a problem in Italy.' 'High level training centres are needed in the universities.' 'Additional courses in universities for students and for industry researchers.'

Japan: 'Drug discovery requires 'what' should be synthesised and 'how'. Japanese students are well trained in 'how'. University education must focus more on the 'what'.' 'In Japan, the majority of medicinal chemists are hired with a Master's degree from Faculties of Pharmacy. In future we will require some scientists with a PhD.' 'Establish medicinal chemistry departments in universities for postgraduate training.'

UK: 'Introduce a four year Bachelor's course (three years chemistry and one year medicinal chemistry).' 'Adapt undergraduate courses to substitute medicinal chemistry topics for some inorganic or physical chemistry topics.' 'Do not believe that a medicinal chemist can be produced at university. Organic chemistry is so vast that it should not be diluted with other subjects.'

USA: 'Appoint more medicinal chemistry professors from industry.' 'Provide additional courses to chemistry graduate students in topics related to drug design, eg, biochemistry, biological chemistry, molecular biology, pharmacology, computing skills.' 'Provide summer training in a medicinal chemistry laboratory during undergraduate or graduate studies.' 'Provide university short courses in aspects of drug design to postdoctoral researchers who are working in industry.' 'Improve the capability and desire to work in a team and the ability to identify, prioritize and address commercial issues in addition to science.' 'Reverse the trend in which the number of synthetic organic chemistry professors in the USA is declining due to decreased funding and the number of students taking this subject is also falling.'

**Table VII.** Answers to Question 6 per country: *Suggestions for a medicinal chemistry curriculum.*

| *Subject* | *Percentage number of responses* | | | | |
|---|---|---|---|---|---|
| | *Germany* | *Italy*[a] | *Japan* | *UK*[b] | *USA* |
| Biochemistry or DMPK[c] | 17 | 11 | 9 | 40 | 27 |
| Pharmacology or physiology | 17 | 22 | 0 | 40 | 24 |
| Synthetic organic chemistry | 17 | 67 | 4 | 0 | 24 |
| Modelling or QSAR | 17 | 11 | 17 | 7 | 21 |
| Drug design | 0 | 0 | 0 | 7 | 18 |
| Enzymology | 0 | 0 | 0 | 0 | 15 |
| Biological chemistry | 8 | 0 | 4 | 7 | 15 |
| Molecular biology | 0 | 0 | 0 | 20 | 15 |
| Toxicology | 17 | 0 | 4 | 7 | 9 |
| Microbiology | 8 | 11 | 0 | 7 | 6 |
| No answer | 45 | 22 | 0 | 22 | 18 |

[a]Only two responses from Italy identified specific topics; three replied in a general manner about the training required: eg, BS or MS in organic chemistry plus PhD in organic or medicinal chemistry, followed by postdoctoral experience in medicinal chemistry or in a big pharmaceutical company. [b]Three replies indicated that medicinal chemistry should not be studied at university at all. [c]DMPK = drug metabolism and pharmacokinetics.

## Additional remarks

Some interesting remarks were written on the forms which illustrated a very wide spectrum of viewpoints, some very forcefully expressed. The view was indicated many times that a strong background in synthetic organic chemistry is essential for success. It is a skill that cannot be learned on the job. At one extreme was the statement 'we do not ask for additional education in medicinal chemistry since we find that this dilutes the understanding of basic principles in chemistry.' Furthermore several answers indicated that medicinal chemistry and drug research is better taught in industry than in academic institutions. Indeed, as one respondent indicated: 'We only hire organic chemists. We have occasionally interviewed medicinal chemists but found their organic chemistry to be weak. We are not set up to teach them organic chemistry but we have much experience in teaching the principles of medicinal chemistry to organic chemists.' In contrast, one respondent stated: 'I want to emphasize that the role of a medicinal chemist is to solve biological problems with an exact science in an interdisciplinary environment. The chemists must not look at themselves in isolation. If they do, they will end up being told what to do! This is one of the underlying problems as to why medicinal chemists are getting short shrift in many companies now. We collectively are to blame for this!' Another indicated: 'most of our PhD chemists have strong organic backgrounds and look for similar chemists who can learn medicinal chemistry. It would be preferable to have a better balance.' It would be very difficult to reconcile such divergent views!

Perhaps these viewpoints arise out of the current highly specialised and sophisticated organisation of research in the big companies. This was succinctly expressed by a respondent who stated: 'Increasingly drug discovery is dependent on the application of many skills and disciplines at the state-of-the-art level. This is best achieved by the efficient functioning of a group of experts, each highly skilled in the requisite discipline. This dictates the training of such specialists and they only need to be sufficiently knowledgeable in the other disciplines to allow effective team interaction.'

## Information about the respondents

The respondents vary in industrial medicinal chemistry experience with 10–25 years being representative (table VIII). In the USA, 50% had > 20 years experience whereas in Germany, Japan and the UK the percentage having such extensive experience was substantially lower (28–33%). There was a wide range in their levels of responsibility, all the way from researcher, through manager to head or director of medicinal chemistry, to vice president. The numbers of PhD or equivalent chemists reporting to them (managerially) ranged mainly from 5 to 25. Not surprisingly, a very high proportion received their formal training in synthetic organic chemistry: a significant minority (20%) had combined their chemistry with biochemistry, pharmacology, pharmacy, or medicinal chemistry. The companies represented are mainly big and multinational.

## Discussion

In the research-based pharmaceutical companies most medicinal chemists are employed in the design and synthesis of new compounds for biological testing as part of the new drug discovery process. It was obvious that this was the basis for the replies received. The overwhelming response was clear. The companies wish to recruit first-rate synthetic organic chemists. Since synthetic organic chemistry is a more basic science it must be made secure; medicinal chemistry is viewed as being capable of being grafted on, but the points at issue are when and how. There are many diverse opinions. One extreme view expressed several times was that medicinal chemistry can be learned by experience and that there is no need to teach it in university. If it is taught it must not be at the expense of specialist organic chemistry. Most responses were less extreme. Senior chemists responsible for hiring new medicinal chemists looked favourably on additional courses, such as biochemistry, biological chemistry, pharmacology, physiology, molecular biology, QSAR and molecular modelling.

One issue that was posed by a substantial number of the respondents was whether one can 'teach medicinal chemistry' at university or has it to be learned on the job since drug design is an applied subject. This seems to be a misunderstanding by some respondents about the aim of the questionnaire and, indeed, about the process of education. It takes many years to gain sufficient experience 'on the job' for drug design! One answer indicated 15 years! The point of teaching some ideas and methods is not to replace experience but to enhance it. By introducing new ideas and concepts early in the education process students become imprinted and this removes barriers to future learning and modifies the way they think. This is especially true where other scientific disciplines are concerned and this is very important for effective communication across the disciplines. The purpose of teaching is to shorten the time it takes to achieve perceptive understanding and to get the scientist to the creative cutting edge much faster. Nowadays, the

**Table VIII.** Information about the respondents; numbers of replies per country.

| | *Germany* | *Italy* | *Japan* | *UK* | *USA* |
|---|---|---|---|---|---|
| *Experience (number of years)* | | | | | |
| <5 | 0 | 0 | 1 | 0 | 0 |
| 5–9 | 0 | 2 | 6 | 3 | 4 |
| 10–20 | 8 | 3 | 8 | 10 | 12 |
| >20 | 4 | 4 | 7 | 5 | 16[a] |
| *Position* | | | | | |
| VP or Research Director | 2 | | 6 | | 4 |
| Director or Head of Medicinal Chemistry | 10 | 8 | 3 | 13 | 22 |
| Senior researcher | | 1 | 6 | | 4 |
| Manager | | | 6 | 3 | |
| Researcher | | | 2 | 1 | |
| No information | | | | 1 | 2 |
| *Responsibility (number of PhDs or equivalent within area of responsibility)* | | | | | |
| <5 | 0 | 1 | 8 | 3 | 2 |
| 5–9 | 4 | 4 | 6 | 4 | 9 |
| 10–20 | 2 | 3 | 5 | 4 | 6 |
| >20 | 5[b] | 1 | 2 | 7 | 12[c] |
| *Educational background* | | | | | |
| Organic chemistry | 10 | 7 | 16 | 18 | 27 |
| plus biochemistry | 2 | 0 | 4 | 1 | 1 |
| plus pharmacology | 2 | | | | 2 |
| plus medicinal chemistry | | 1 | | | 3 |
| plus pharmacy | | 1 | 2 | | |
| plus bioorganic | | 1 | | | 1 |
| Other | | 2[d] | | | 7[e] |

[a]Four replies indicated >30 years experience; [b]four replies indicated responsibility for 30–40 PhDs, one reply indicated responsibility for 60 PhDs; [c]four replies indicated responsibility for 31–40 PhDs, two replies indicated responsibility for >40 PhDs; [d]two replies indicated industrial chemistry as educational background; [e]replies indicated physical organic chemistry (4), medicine (1), biological chemistry (1) or pharmacognosy (1) as part of their educational background.

molecular basis for drug design is expanding so rapidly that scientists cannot afford the luxury of taking ten or more years for 'on the job' training. The point is surely not whether one can teach how to design drugs but whether one can teach some principles and language to be used as tools and where this might be done most efficiently. What these tools are will provide the basis for a curriculum in medicinal chemistry.

The practice of medicinal chemistry and its role in drug research has been continuously changing over the years due to changes in technology, scientific understanding, and the approaches to drug research. Forty years ago, research in the pharmaceutical industry was dominated by organic chemists. Medicinal chemists were rather rare and were often referred to as pharmaceutical chemists. Indeed, recognition of the science of medicinal chemistry as a chemical subdiscipline was in its infancy. The *Journal of Medicinal Chemistry* emerged only in 1957. In the search for new types of drug action, most leads were generated by screening. Since then we have had a period in which a more rational approach has emerged based upon a knowledge of enzymes and receptors as targets. In this period the dialogue between the chemist and biologist became very important and chemists had to learn much more about the biological targets and how to match the chemistry of drugs to bind to these targets.

We have now entered another phase where technology has provided the opportunity for automated screening against a range of biological targets using radioligand binding or enzyme assays, in addition to screens against microorganisms. When a new lead is generated one requires outstanding organic chemistry to follow it up as rapidly as possible by synthesizing analogues. Surely, one has also to select the target molecules for synthesis but the planning requires a brief time compared with the time spent on actually synthesizing them. Only a few medicinal chemistry

**Table IX.** Summations of answers to Question 3 by country: *If you were to employ a synthetic organic chemist who will join your company to become a medicinal chemist, state A: your priorities for additional education against the listed subjects (rated according to priority where 1 is low and 5 is high priority) and B: indicate the stage at which each subject should be taught, where a = undergraduate, b = graduate student, c = postdoctoral appointment, d = only in industry.*

| *Subject* | *Priorities for additional education*[a] | | | | | | *Stage for teaching* | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *1* | *2* | *3* | *4* | *5* | *Score* | *a* | *b* | *c* | *d* |
| **Germany** (11 replies) | | | | | | | | | | |
| Synthetic methodology | 0 | 0 | 0 | 0 | 11 | 55 | 7 | 8 | 5 | 0 |
| Mechanistic synthesis | 0 | 0 | 2 | 6 | 3 | 45 | 6 | 9 | 2 | 0 |
| Physical organic chemistry | 1 | 3 | 3 | 3 | 0 | 28 | 8 | 6 | 1 | 0 |
| Biological chemistry | 0 | 0 | 7 | 1 | 3 | 40 | 1 | 9 | 4 | 3 |
| QSAR | 1 | 5 | 4 | 1 | 0 | 27 | 0 | 5 | 4 | 3 |
| Computational modelling | 0 | 2 | 2 | 5 | 2 | 40 | 0 | 7 | 6 | 4 |
| Analytical chemistry | 2 | 1 | 6 | 1 | 0 | 26 | 8 | 5 | 1 | 0 |
| Process chemistry | 3 | 5 | 1 | 0 | 1 | 21 | 1 | 1 | 1 | 9 |
| Knowledge of drug action | 0 | 0 | 5 | 2 | 3 | 38 | 2 | 4 | 3 | 5 |
| Drug metabolism | 1 | 0 | 5 | 4 | 0 | 32 | 1 | 3 | 2 | 5 |
| Pharmacokinetics | 1 | 2 | 5 | 2 | 0 | 28 | 0 | 4 | 2 | 5 |
| Prodrugs | 1 | 1 | 5 | 3 | 0 | 30 | 1 | 3 | 3 | 4 |
| Principles of pharmacology | 1 | 1 | 1 | 5 | 2 | 36 | 0 | 5 | 5 | 1 |
| Physiology | 1 | 1 | 6 | 2 | 0 | 29 | 1 | 4 | 3 | 3 |
| Molecular biology | 0 | 0 | 5 | 1 | 5 | 44 | 1 | 8 | 3 | 2 |
| Toxicology | 1 | 3 | 4 | 2 | 0 | 27 | 2 | 3 | 3 | 5 |
| Microbiology | 1 | 4 | 3 | 1 | 1 | 27 | 1 | 4 | 2 | 3 |
| Pharmaceutics | 2 | 6 | 2 | 0 | 0 | 20 | 0 | 1 | 0 | 9 |
| Maximum score | | | | | | 55 | | | | |
| Minimum score | | | | | | 11 | | | | |
| **Japan** (22 replies) | | | | | | | | | | |
| Synthetic methodology | 1 | 1 | 3 | 5 | 12 | 92 | 4 | 16 | 5 | 0 |
| Mechanistic synthesis | 0 | 3 | 5 | 9 | 5 | 82 | 4 | 17 | 3 | 0 |
| Physical organic chemistry | 3 | 4 | 9 | 4 | 2 | 64 | 10 | 9 | 3 | 1 |
| Biological chemistry | 0 | 2 | 3 | 11 | 6 | 87 | 7 | 10 | 7 | 0 |
| QSAR | 0 | 3 | 3 | 12 | 4 | 83 | 2 | 9 | 8 | 4 |
| Computational modelling | 1 | 3 | 6 | 8 | 4 | 77 | 2 | 9 | 8 | 4 |
| Analytical chemistry | 4 | 4 | 8 | 5 | 1 | 61 | 13 | 8 | 0 | 1 |
| Process chemistry | 2 | 8 | 9 | 1 | 2 | 59 | 4 | 4 | 2 | 12 |
| Knowledge of drug action | 0 | 0 | 7 | 7 | 7 | 84 | 4 | 12 | 3 | 3 |
| Drug metabolism | 0 | 2 | 9 | 7 | 4 | 79 | 5 | 10 | 2 | 5 |
| Pharmacokinetics | 0 | 3 | 4 | 12 | 2 | 76 | 4 | 10 | 6 | 3 |
| Prodrugs | 1 | 6 | 7 | 5 | 3 | 65 | 3 | 8 | 3 | 9 |
| Principles of pharmacology | 1 | 3 | 9 | 7 | 1 | 67 | 6 | 9 | 1 | 6 |
| Physiology | 0 | 5 | 11 | 4 | 2 | 69 | 11 | 7 | 2 | 2 |
| Molecular biology | 0 | 2 | 5 | 10 | 5 | 64 | 6 | 12 | 4 | 2 |
| Toxicology | 2 | 6 | 9 | 4 | 1 | 62 | 11 | 4 | 2 | 5 |
| Microbiology | 4 | 4 | 9 | 3 | 1 | 56 | 10 | 8 | 1 | 3 |
| Pharmaceutics | 4 | 10 | 5 | 1 | 1 | 48 | 9 | 4 | 0 | 9 |
| Maximum score | | | | | | 110 | | | | |
| Minimum score | | | | | | 22 | | | | |
| **Italy** (9 replies) | | | | | | | | | | |
| Synthetic methodology | 0 | 0 | 1 | 3 | 5 | 40 | 2 | 5 | 2 | 0 |
| Mechanistic synthesis | 0 | 1 | 3 | 2 | 3 | 34 | 1 | 5 | 2 | 0 |
| Physical organic chemistry | 1 | 3 | 2 | 3 | 0 | 25 | 1 | 7 | 2 | 0 |
| Biological chemistry | 0 | 3 | 4 | 1 | 0 | 22 | 0 | 6 | 2 | 0 |
| QSAR | 1 | 1 | 2 | 1 | 3 | 28 | 0 | 1 | 6 | 1 |
| Computational modelling | 0 | 4 | 1 | 2 | 2 | 29 | 0 | 1 | 6 | 1 |
| Analytical chemistry | 0 | 3 | 0 | 5 | 0 | 26 | 1 | 4 | 2 | 1 |
| Process chemistry | 0 | 2 | 4 | 2 | 0 | 24 | 0 | 1 | 1 | 6 |
| Knowledge of drug action | 2 | 1 | 3 | 2 | 1 | 21 | 0 | 5 | 3 | 1 |
| Drug metabolism | 0 | 4 | 2 | 2 | 0 | 20 | 0 | 3 | 4 | 1 |
| Pharmacokinetics | 2 | 3 | 3 | 0 | 0 | 17 | 0 | 1 | 4 | 3 |
| Prodrugs | 0 | 3 | 3 | 2 | 0 | 23 | 0 | 2 | 5 | 1 |
| Principles of pharmacology | 0 | 3 | 3 | 0 | 23 | 0 | 6 | 2 | 0 | |
| Physiology | 1 | 5 | 1 | 0 | 0 | 14 | 2 | 3 | 2 | 0 |
| Molecular biolog | 1 | 2 | 3 | 0 | 2 | 24 | 1 | 2 | 4 | 1 |
| Toxicology | 2 | 4 | 1 | 0 | 0 | 13 | 1 | 0 | 5 | 1 |
| Microbiology | 4 | 0 | 3 | 0 | 0 | 13 | 1 | 1 | 4 | 1 |
| Pharmaceutics | 3 | 1 | 3 | 0 | 0 | 14 | 0 | 0 | 2 | 5 |
| Maximum score | | | | | 45 | | | | | |
| Minimum score | | | | | 9 | | | | | |

**Table IX.** Continued

| *Subject* | *Priorities for additional education*[a] | | | | | | *Stage for teaching* | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *1* | *2* | *3* | *4* | *5* | *Score* | *a* | *b* | *c* | *d* |
| **UK** (17 replies) | | | | | | | | | | |
| Synthetic methodology | 0 | 0 | 0 | 0 | 17 | 85 | 13 | 11 | 7 | 4 |
| Mechanistic synthesis | 0 | 0 | 0 | 3 | 14 | 82 | 15 | 7 | 3 | 2 |
| Physical organic chemistry | 1 | 0 | 5 | 5 | 6 | 66 | 10 | 7 | 4 | 3 |
| Biological chemistry | 2 | 1 | 3 | 8 | 4 | 65 | 12 | 7 | 6 | 7 |
| QSAR | 2 | 4 | 5 | 2 | 5 | 62 | 2 | 2 | 5 | 12 |
| Computational modelling | 0 | 2 | 10 | 5 | 1 | 59 | 3 | 9 | 11 | 9 |
| Analytical chemistry | 8 | 4 | 3 | 1 | 1 | 34 | 11 | 2 | 2 | 2 |
| Process chemistry | 12 | 3 | 2 | 0 | 1 | 29 | 3 | 3 | 0 | 10 |
| Knowledge of drug action | 2 | 2 | 3 | 4 | 7 | 66 | 7 | 5 | 3 | 7 |
| Drug metabolism | 3 | 1 | 4 | 6 | 4 | 61 | 4 | 3 | 4 | 10 |
| Pharmacokinetics | 3 | 1 | 6 | 6 | 2 | 59 | 2 | 2 | 3 | 12 |
| Prodrugs | 5 | 3 | 8 | 1 | 1 | 44 | 2 | 0 | 2 | 14 |
| Principles of pharmacology | 2 | 2 | 3 | 6 | 5 | 64 | 3 | 4 | 3 | 10 |
| Physiology | 3 | 9 | 2 | 1 | 3 | 46 | 6 | 1 | 3 | 8 |
| Molecular biology | 1 | 2 | 8 | 4 | 3 | 60 | 5 | 4 | 6 | 7 |
| Toxicology | 5 | 6 | 4 | 2 | 1 | 42 | 2 | 3 | 2 | 11 |
| Microbiology | 7 | 4 | 5 | 1 | 1 | 39 | 4 | 4 | 1 | 9 |
| Pharmaceutics | 7 | 10 | 1 | 0 | 0 | 30 | 2 | 1 | 0 | 13 |
| Maximum score | | | | | | 85 | | | | |
| **USA** (30 replies) | | | | | | | | | | |
| Synthetic methodology | 0 | 0 | 1 | 3 | 26 | 145 | 10 | 27 | 14 | 3 |
| Mechanistic synthesis | 0 | 1 | 1 | 13 | 15 | 132 | 12 | 24 | 10 | 3 |
| Physical organic chemistry | 0 | 2 | 14 | 9 | 5 | 107 | 12 | 24 | 7 | 2 |
| Biological chemistry | 1 | 5 | 7 | 10 | 7 | 107 | 7 | 12 | 11 | 8 |
| QSAR | 1 | 5 | 12 | 9 | 3 | 98 | 0 | 9 | 9 | 15 |
| Computational modelling | 1 | 2 | 18 | 7 | 2 | 97 | 0 | 12 | 15 | 12 |
| Analytical chemistry | 6 | 7 | 11 | 4 | 1 | 71 | 18 | 9 | 2 | 3 |
| Process chemistry | 3 | 12 | 10 | 4 | 1 | 78 | 0 | 6 | 3 | 24 |
| Knowledge of drug action | 2 | 6 | 10 | 9 | 4 | 108 | 4 | 5 | 8 | 20 |
| Drug metabolism | 3 | 9 | 8 | 8 | 2 | 87 | 0 | 3 | 6 | 22 |
| Pharmacokinetics | 4 | 9 | 9 | 5 | 3 | 84 | 0 | 3 | 5 | 22 |
| Prodrugs | 7 | 6 | 8 | 7 | 2 | 81 | 0 | 1 | 5 | 25 |
| Principles of pharmacology | 4 | 6 | 5 | 11 | 4 | 95 | 1 | 5 | 9 | 19 |
| Physiology | 7 | 11 | 9 | 3 | 0 | 68 | 7 | 5 | 4 | 17 |
| Molecular biology | 4 | 5 | 12 | 4 | 4 | 86 | 6 | 9 | 11 | 14 |
| Toxicology | 9 | 8 | 10 | 2 | 1 | 68 | 2 | 2 | 3 | 23 |
| Microbiology | 13 | 11 | 4 | 2 | 0 | 55 | 8 | 5 | 2 | 17 |
| Pharmaceutics | 13 | 8 | 8 | 1 | 0 | 57 | 2 | 1 | 2 | 24 |
| Maximum score | | | | | | 150 | | | | |
| Minimum score | | | | | | 30 | | | | |

[a]The number of responses for each subject is shown for the respective priorities and stage for teaching. Returns for the latter add up to more than 100% because many respondents indicated that subjects should be acquired at more than one educational stage. The score represents the sums of the number of answers times the priority values.

experts may be needed to provide the drug-design 'know-how'. It must be appreciated, however, that this 'know-how' of drug design has now become even more important. The possibility of using techniques as in combinatorial chemistry to rapidly generate large numbers of compounds for structure optimization places an even greater premium on the ability to conduct a perceptive structure–activity analysis of the data being generated. Furthermore it has become even more critical in drug design to incorporate at an early

stage the requirements for achieving satisfactory pharmacokinetic behaviour of drugs in vivo. Thus medicinal chemists need a great awareness of the chemical factors affecting drug distribution and drug toxicity. Organic chemists enter the industry completely unaware of these issues. Medicinal chemists are required to analyse and solve them. In the current climate of large research teams and specialists a typical team will probably include a few experts in NMR or mass spectroscopy, crystallography, chemical computation and modelling, a few experienced medicinal chemists to relate biology to structure–activity analysis and to solve absorption, distribution, metabolism, and excretion problems, but the majority of the team will be the many organic chemists involved in the synthesis. Of course, being in a team implies that the various sub-disciplines are mutually supportive. The medicinal and organic chemists are not working in isolation but are strongly interactive and helping one another solve the many technical problems that arise. Perhaps this situation underlies the strong bias towards organic chemists revealed in the replies to the questionnaire.

It is also important to note that the questionnaire was sent to the research directorate of large international pharmaceutical companies. These possess the large research teams. Small companies generally do not have a wide range of specialists. They are much more dependent on generalists who can cover various aspects, eg, to have productive dialogue with biologists, understand drug-design and structure–activity analysis, and be able to synthesize compounds. Furthermore they usually lack the infrastructure to provide company training in medicinal chemistry. Probably, therefore, their requirements and attitudes towards university-trained medicinal chemists will be quite different.

## The teaching of medicinal chemistry

As indicated by the replies to the questionnaire, many of the large research-based pharmaceutical companies have established internal courses to teach the principles of medicinal chemistry to their newly hired organic chemists. There are also the one week residential intensive postgraduate courses [12] held at, eg, University of Kent in Canterbury, UK, Drew University, Madison, New Jersey, USA, Leiden-Amsterdam, The Netherlands and Leysin, Switzerland. Their great popularity (they are generally oversubscribed) attests to the support given by companies in sending their young medicinal chemists to attend.

Some universities provide the opportunity for postgraduate chemistry students to attend courses appropriate to medicinal chemistry during their research training. Generally these have departments of medicinal chemistry and may be in schools or faculties of pharmacy. There is a general perception amongst organic chemists, however, that organic chemistry in schools of pharmacy is not of the highest standard and therefore it would be advantageous if, in some way, there could be a working collaboration between the departments of medicinal chemistry and organic chemistry. This was clearly apparent in the replies to the questionnaire. It is proposed to pursue this enquiry by taking it to the universities which teach medicinal chemistry.

## References and notes


1 Membership of the Section Committee was JG Topliss (President), N Koga (Vice-President), WD Busse (Secretary), CG Wermuth (past President), CR Ganellin, LA Mitscher

2 The members were CR Ganellin (Chairman), WD Busse (Bayer, Wuppertal, Germany), P Lindberg (Astra, Hässle, Mölndal, Sweden), LA Mitscher (University of Kansas, USA), G Tarzia (University of Urbino, Italy), CG Wermuth (Université Louis-Pasteur, Strasbourg, France) and R Ziegler (Sandoz, Basel, Switzerland)

3 We are grateful to D Twomey and M Ganellin for helpful discussion about construction of the questionnaire

4 We thank N Koga (Daiichi Pharmaceutical) and J Ide (Sankyo) for arranging distribution of the questionnaire in Japan

5 We thank T Krämer (Bayer AG, Wuppertal) for assistance with the analysis of the returned answers

6 WD Busse and CR Ganellin (1993) In: *Trends in Drug Research* (Claassen V, ed) Elsevier, Amsterdam, 1993, 305–315

7 Letters and the questionnaire were sent to companies in France and Italy by CG Wermuth and G Tarzia respectively

8 Letters and the questionnaire were sent to US companies by LA Mitscher or JG Topliss

9. CR Ganellin, LA Mitscher, JG Topliss (1995) In: *Annual Reports of Medicinal Chemistry* (Bristol J, ed) ACS, Vol 30, Ch 33, 329–338

10 T Rotunda (1994) Requisiti e Formazione professionale del Chimico Farmaceutico dell Industria, XI Convegno Nazionale, Divisione di Chimica Farmaceutica, Societa Chimica Italiana, Bari, 2–5 October 1994

11 CG Wermuth, CR Ganellin, R Imhof, P Lindberg, LA Mitscher (1996) *Glossary of Terms Used in Medicinal Chemistry. Pure Appl Chem* (in press)

12 CR Ganellin (1995) *Syllabus for a Short Postgraduate Course in Medicinal Chemistry*, Chemistry International, Blackwell Science, Oxford, 17, 212–214