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Point of view

University education of medicinal chemists: comparison of eight countries

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Abstract – Medicinal chemists are mainly taught in faculties or schools of pharmacy and are available for employment. Yet major pharmaceutical research companies seek organic chemists, rather than medicinal chemists, for new drug discovery. This apparent contradiction led the Medicinal Chemistry Section of IUPAC to send a questionnaire regarding postgraduate academic education for medicinal chemists to the faculties or schools of pharmacy in eight countries, namely, France, Germany, Italy, Japan, Spain, Switzerland, UK and USA. The questionnaire aimed to elicit information about postgraduate medicinal chemistry students, their courses and training, and the occupations taken up after graduation. The replies representing 109 medicinal chemistry departments or sections have been analysed and the results are presented to provide a data base on modern medicinal chemistry curricula for comparative purposes. The information should help guide discussion of the optimum paths to be followed by students in preparation for their careers. The evidence suggests that academic training of medicinal chemists equips them to enter a wide range of occupations, many of which are in industry. © 2000 Éditions scientifiques et médicales Elsevier SAS

postgraduate education / postdoctoral research / medicinal chemistry / presentation skills / occupation / curricula / industry

1. Introduction

How to become a medicinal chemist? This question is of interest to many aspiring chemists wishing to become professionally involved in the design and synthesis of potential new drug molecules. The pharmaceutical industry is where most new chemical entities are developed into therapeutic products. They are a major employer of organic and medicinal chemists.

When leading medicinal chemists and research directors in the major international pharmaceutical companies engaged in research and development were asked about this question, their responses were very similar. They were sent a questionnaire by the IUPAC (International Union of Pure and Applied Chemistry) Medicinal Chemistry Section [1]. Over 90% of the answers indicated that the preferred entry of staff for medicinal chemistry was as organic chemists rather than specialists of medicinal chemistry. Some conceded that it would be helpful for staff to have had some acquaintance with biological subjects such as biochemistry, pharmacology, and physiology [2–4].

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It was stated rather forcefully by the respondents that the most important educational background that they required of the new chemists was strong training in synthetic organic chemistry and that most other necessary skills could be learned on the job. Surprisingly little interest was indicated for having chemists with formal academic training in medicinal chemistry, or for chemists trained in organic synthesis but also having significant education in biological subjects.

Clearly, the overwhelming view that prevails in industrial pharmaceutical research is 'if you cannot make the compound then you cannot test it'. However what a chemist selects to make is also critical; so presumably the view must exist that there are already sufficiently experienced medicinal chemists present in the companies to assist newly hired chemists in the selection of target compounds. The balance required between these aspects of expertise and the ease of acquiring expertise is obviously debatable.

Whatever the views on this subject that may be held by academic medicinal chemists, they have to face the industrial viewpoint if they are involved in training medicinal chemists for possible industrial employment.

Having asked the customer about their requirements for medicinal chemists it was clearly appropriate to ask the supplier, i.e. the academic institutions where medicinal chemists receive formal education.

Historically, formal university education in medicinal chemistry takes place primarily in faculties or schools of pharmacy. Here, medicinal chemistry is only one of a variety of subjects taught at undergraduate level where the primary focus is education for future practising pharmacists.

The undergraduate medicinal chemistry is usually taught by academic staff (i.e. faculty members) who are practising medicinal chemists in the sense that they are usually supervising postgraduate students involved in studying a medicinal chemistry topic at research level, often for a Ph.D. requirement, and/or postdoctoral researchers.

It is of interest therefore to find out where such academically research trained medicinal chemists fit into the job spectrum of professionally active medicinal chemists. To this end a questionnaire was sent [5] to medicinal chemistry faculty members in faculties or schools of pharmacy in various countries.

There are many differences between countries in the way that pharmacy courses are organised so that it becomes quite difficult to dissect out the medicinal chemistry component to make clear comparisons internationally.

1.1. Undergraduate and postgraduate studies of medicinal chemistry in faculties of pharmacy in the various countries

– France: there are 24 faculties of pharmacy in France. The pharmacy course lasts 6 years to train a qualified pharmacist. During the 3rd and 4th years the students study for their Maîtrise des Sciences Biologiques et Médicales (MSBM) but this may change soon. After the MSBM the students may study for the Diplôme d'Etudes Approfondies (DEA) which prepares them to undertake research work (considered as being equivalent to an M.Sc.) The DEA curriculum comprises lecture courses and a research project which includes the presentation of a written report. After this, the student is permitted to enter the Ph.D. course which normally takes 3–4 years. In France, medicinal chemistry is referred to as chimie thérapeutique or pharmacochimie.

– Germany: the education of German pharmacists is regulated by law ('Approbationsordnung' of 1989) which requires that all universities with Pharmaceutical Institutes (there are 23) offer the same type of lectures and practical courses. The course lasts 4 years plus 1 year of pharmacy practice. The final degree is a state examination which leads to registration ('Approbation'). A student may then enter a Ph.D. course in natural science which ideally takes 3 years. Pharmaceutical chemistry encompasses medicinal chemistry and analytical chemistry.

– Italy: the Italian system for higher education is structured into two levels. The first one confers the 'Laurea' which takes 5–7 years and includes an experimental thesis. The second level leads to the 'Dottorato di Ricerca' and involves a 3 year research project that must result in a thesis and published articles; hence, this appears to be equivalent to a Ph.D. degree. Each university in Italy has a faculty of pharmacy and these faculties operate two curricula, one which is specifically for pharmacists and one which is explicitly directed to medicinal chemistry, called 'Chemical and Pharmaceutical Technologies' (CTF).

The maximum number of full-time doctoral students nationally in Italy is determined annually by the Italian Ministry of Education and Scientific Research. For example, in November 1997 the maximum number of doctoral students nationwide permitted for admission to the faculties of pharmacy was set at 107, of which 65 were distributed among 21 specific programmes in medicinal or pharmaceutical chemistry and the remainder were for 16 specific programmes in biochemistry or pharmacology. The 21 specific medicinal chemistry programmes were distributed among 18 universities, each of which was sent a questionnaire. There are actually 23 universities in Italy but at the time of the questionnaire 5 of these operated their research programmes in medicinal chemistry in association with one of the 18.

– Japan: there are three types of university in Japan which teach pharmaceutical sciences. There are seven old established Imperial Universities and six of these have an undergraduate faculty and graduate school in pharmaceutical sciences. There are more than 100 national and public universities, which were established after the end of the second world war and 11 of these have a faculty of pharmaceutical sciences which also include research orientated graduate schools. There are also many hundreds of private universities of which 29 have a faculty of pharmaceutical science; these also maintain a research orientation through a graduate school.

Irrespective of the type of university, the undergraduate programme (4 years) is controlled by the Ministry of Education. Graduates from the 4 year course take the government examination for qualified pharmacists. However, there has been a controversial debate over whether to extend the training period (4 years) for the national examination to the 6 year M.Sc. course which has yet to be finalized.

The graduate schools encompass the first 2 years for an M.Sc. and an additional 3 years for a Ph.D. The courses are so diverse, ranging from physicochemistry through to biotechnology, that in Japan the description pharmaceutical sciences is more widely used than pharmacy. Pharmacy is one of the pharmaceutical sciences.

– Spain: there are 14 schools of pharmacy in Spain. Five years are needed to obtain a degree (licentiateship) in pharmacy. Medicinal chemistry, called pharmaceutical chemistry, is studied in the third year of the licentiateship and is a required course for all students. There is no limit to the number of students, which according to the academic authorities is quite essential in present times. All the schools of pharmacy have Ph.D. programmes in medicinal chemistry, which normally take 3–4 years. The Ph.D. students in medicinal chemistry may be pharmacists, chemists or biologists.

– Switzerland: studies in pharmacy and pharmaceutical sciences can be undertaken in three institutions: The University of Basel, the Ecole Romande de Pharmacie in Geneva and Lausanne, and the ETH in Zurich. The first graduation is a Federal Diploma which takes 5 years to achieve and is clearly above a British B.Sc., and comes close to an M.Sc. degree. An ongoing reform of the (federally regulated) studies in pharmacy still does not provide for the establishment of an independent curriculum in medicinal chemistry. The Universities of Geneva and Lausanne together organize a postgraduate diploma (DES = Diplôme d'Etudes Supérieures) in chemistry for first year Ph.D. students where a 50 hour course in medicinal chemistry appears as an option. Ph.D.s in medicinal chemistry can be undertaken in the laboratories/Institute of Medicinal Chemistry of the three schools/departments of pharmacy. Such a Ph.D. curriculum is open to pharmacists and chemists and generally takes around 4–5 years. The title obtained is either a doctorate in sciences or in pharmaceutical sciences.

– UK: there are 16 faculties or schools of pharmacy and until recently the first degree, B.Pharm. (bachelor of pharmacy) was a 3 year course. Since October 1997 it has been extended to a 4 year course (M.Pharm., a master of pharmacy). However, at the date of the questionnaire, the undergraduate course still lasted for only 3 years. Students then have to practice pharmacy under supervision for 1 year (either dispensing or in industry, or undertaking research) before they are admitted as qualified pharmacists by the 'Royal Pharmaceutical Society of Great Britain'. The latter society has the responsibility for maintaining standards of practise.

Medicinal chemistry can also be taken as an option in many of the chemistry departments unconnected with pharmacy. There is, however, considerable variation in course content. Some chemistry departments offer just a half unit (about 30 lectures) of 'chemistry of drugs' which may only relate to drug synthesis. Others offer a combined degree in chemistry with pharmacology whilst a few offer a course which encompasses chemistry, biochemistry, physiology, pharmacology and drug design. Currently, students may opt for a bachelor's degree (B.Sc.) after 3 years, or take a 4 year course which may be called a master of chemistry (M.Chem.) or master of science (M.Sci.), which includes a research project requiring a written report to obtain what is now considered to be the main graduate qualification for chemists. This, however, is not to be confused with the postgraduate master's degree qualification, M.Sc. which is a one year degree comprised of lecture courses, a research project, and a written thesis.

Until recently a B.Sc. passed at a high level provided the entry qualification for a Ph.D. degree course. Now, the entry requirement to a Ph.D. is an M.Chem., M.Sci. or M.Pharm. The Ph.D. course normally lasts 3 years but many students take longer than this (up to another year) before presenting their thesis.

– USA: there are 36 departments of medicinal chemistry listed in the American Chemical Society Directory of Graduate Research (1995) and all are associated with a school or faculty of pharmacy. Undergraduate courses in medicinal chemistry are components of a bachelor's degree in pharmacy (B.S. Pharmacy, 5 years) and the Doctor of Pharmacy (Pharm.D., 6 years) degree. A bachelor's degree in medicinal chemistry (B.S. Medicinal Chemistry, 4 years) is also offered by some departments but the number of students taking such degree courses is very small.

Ph.D. degrees in medicinal chemistry typically take 5–6 years following an undergraduate degree in either chemistry, pharmacy, medicinal chemistry, biochemistry or biology. Thesis topics for the degree may involve synthesis, structure–activity relationships, computational drug design and modelling, drug metabolism, enzymology, analysis, natural product chemistry, and biochemistry or some combination of these. An M.S. degree in medicinal chemistry with an experimental thesis requires at least a 2 year programme. A high proportion of M.S. degrees granted are awarded to students who are unable or unwilling for various reasons, to complete an intended Ph.D. degree. Graduates at the doctoral level far outnumber those at the masters level.

2. Results

2.1. Questionnaire sent to university medicinal chemistry departments

A questionnaire was first sent out to all 36 departments of medicinal chemistry in the USA which undertake postgraduate research. A total of 29 replies was received (approximately 80% response); these were analysed and have already been reported on [6].

The questionnaire was also sent to other countries but it was modified somewhat to make it more general (i.e., less directly orientated towards the USA) and to seek some additional information. It was sent to medicinal chemistry professors in the faculties or in schools of pharmacy in Western Europe (France, Germany, Italy, Spain, Switzerland, UK) and Japan by an appropriate national of the respective country (see footnotes in *table I*). These countries were selected because they have many faculties or schools of pharmacy and a developed pharmaceutical industry with a history of drug discovery. Some other countries with excellent drug discovery traditions, such as Belgium, Denmark, The Netherlands and Sweden were not canvassed because they possess few faculties of pharmacy. The 29 replies from Japan (representing 13 different universities) have already been analysed and reported [7].

The numbers of departments (or faculties) canvassed ranged from three in Switzerland to 45 in Japan (*table I*), with France, Germany, Italy and the UK being 18–24. The response rate was quite good, extending from 29% for Japan to 100% for Switzerland, with Spain being 46% and France, Germany, Italy, UK and USA being 65–81%.

Table I. Numbers of departments asked and responding per country.

Country	Number sent	Number replied	Percentage response
France[a]	24	16	67
Germany[b]	23	15 (30)	65
Italy[c]	18	12	67
Japan[d]	45	13 (29)	29
Spain[e]	13	6	46
Switzerland[f]	3	3	100
UK[g] (A)	14	11	79
(B)	5	4	80
USA[h]	36	29	81

[a] Translated into French, adapted to the French education system, and sent out by Professor O. Lafont (University of Rouen) and Professor A. Marcincal (University of Lille). [b] Sent to the 72 professors of pharmaceutical chemistry by Professor B. Clement, University of Kiel. There were 30 replies from 15 institutions. [c] Translated into Italian and sent out by Professor G. Tarzia, University of Urbino. [d] Sent to the 119 pharmaceutical chemistry professors by Dr T.-H. Kobayashi, Eli Lilly KK with a covering letter in Japanese. There were 29 replies from 13 institutions. [e] Sent out by Professor A. Monge, University of Navarra. [f] Sent out by Dr E. Kyburz (New Swiss Chemical Society, Basel). [g] Sent out by Professor C.R. Ganellin (University College London), A: schools of pharmacy and B: departments of chemistry (not in pharmacy faculties) which provide undergraduates with an option to take a degree in medicinal chemistry. [h] Sent out by Professor L.A. Mitscher (Kansas University) and Professor J.G. Topliss (University of Michigan).

The questionnaire consisted of 15 main questions and was divided into three sections. The first section was aimed at eliciting information about the composition of the postgraduate student body and the nature of the positions taken by the students after completing their studies. There followed a section requesting information about the faculty staff. The third section asked about student course work.

2.2. The students

2.2.1. The numbers of graduate students involved

The aim here was to find out the numbers of Ph.D. students and postdoctoral researchers who are receiving training in a project which is based in medicinal chemistry. In some departments there are also students who take an intermediate research-based qualification such as an M.Sc. or DEA and do not necessarily proceed further to a Ph.D. course; they will have had to do a research project and take courses relevant to medicinal chemistry. It is difficult to identify these clearly because in other departments the Ph.D. students have had to take an

Table II. Number of postgraduate students and postdoctoral research assistants currently enrolled for studies considered primarily for medicinal chemistry.

Country	Number replied[a]	'Masters'[b]	Ph.D.		Postdoctoral		Total Ph.D. + postdoc + 'Masters'
			Total	'Ave.' per institution[c]	Total	'Ave.' per institution[c]	
France	16	73	79	5.0	24	1.5	176
Germany	15	–	349[d]	23.3	36	2.4	385
Italy	12	laurea	82[d]	6.8	16	1.3	98
Japan	13	572	138	10.6	24	1.8	734
Spain	6	56	68	11.3	18	3	142
Switzerland	3	diploma	34[e]	11.3	15	5	51
UK (A)[f]	11	5	116	10.5	40	3.6	161
(B)[g]	4	11	42	10.5	12	3	65
USA	29	66[h]	632	21.8	[j]		

[a] Number of institutions replying. [b] France: DEA; Switzerland: a diploma is the normal graduation degree awarded after 5 years (there is no B.Sc.); UK: M.Sc. [c] Average number per institute. [d] Includes 22 part-time Ph.D. students. [e] Includes 17 part-time students who spend 50% of their time teaching. [f] Schools of Pharmacy. [g] Chemistry departments. [h] 66 M.S. graduates in the past 10 years. [j] Numbers not requested.

intermediate M.Sc. as a prerequisite to continuing to the Ph.D. course. The status of the M.Sc. or its equivalent is especially difficult to compare between different countries.

The number of Ph.D. students in medicinal chemistry per country (*table II*) ranged from 632 in the USA to 34 in Switzerland with Germany having an impressive 349. It must be remembered that these are the numbers obtained from the answers to the questionnaire. They are therefore not the full total for each country because the response rate was not 100%. Examining the average number of medicinal chemistry Ph.D. students per pharmacy department/faculty is revealing. The USA and Germany were similar (22–23), Japan, Spain, Switzerland and the UK were all around half of this number (10–11), whilst Italy (7) and France (5) were lower.

The number of postdoctoral research assistants in medicinal chemistry (*table II*) ranged from 52 in the UK (A + B) to 15 in Switzerland. Unfortunately there are no figures available for the USA. France, Germany, Italy, Japan and Spain had between 16 and 36. Taking the average number per department/faculty showed that France, Germany, Italy and Japan ranged from 1.3–2.4, whereas Spain, Switzerland and the UK had double these numbers (3–5). These low numbers of postdoctoral researchers suggest that they are considered to be a luxury by the funding bodies in these countries.

Table III. Background of the students recruited for Ph.D. programmes in medicinal chemistry. Comparison between actual numbers, given as a percentage, and the average of the ratings[a], by country.

Country	Medicinal chemistry		Chemistry		Pharmacy		Biochemistry		Another country	
	%	rating[a]	%	rating[a]	%	rating[a]	%	rating[a]	%	rating[a]
France	[b]		38	5	38[b]	6	20	4	3	3
Germany	2	6	25	5	59	6	2	4	2	4
Italy[c]	55	7	10	5	11	5	0	2	0	–
Japan[d]	[b]				95				2	
Spain	[b]		33	5	69	6	–	–	–	–
Switzerland[e]	[b]	4		6		4		4		–
UK	8	6	47	7	18	5[f]	6	3	13	4
USA	4	4	47	6	24	4	8	4	48	–

[a] Departments were asked to rate their preference for the background of students admitted to a Ph.D. programme. The scale used was 1 for least preferred to 7 for the most preferred. [b] In these countries medicinal chemistry is covered in the pharmacy programme. [c] Italian total distribution of students only adds up to 76%. [d] In Japan, almost 95% of graduate students have a background in pharmaceutical sciences. [e] In Switzerland the students have a diploma after 5 years, mainly in pharmaceutical sciences. [f] Three of the chemistry departments rated a pharmacy background as 1, i.e. least preferred; if these response ratings are removed then the remaining responses average out as 6.

2.2.2. *Background of the students recruited for Ph.D. programmes in medicinal chemistry*

The questionnaire asked respondents 'when recruiting new students for your Ph.D. programme in medicinal chemistry, what background do you find most attractive? Please score using a scale of 1 = least attractive to 7 = most attractive'. The results are given in *table III*.

A first degree in medicinal chemistry was rated highly (6–7) in all countries except the USA (rated 4). A first degree in chemistry was given the highest rating (6–7) in the UK and USA. A pharmacy qualification was rated highly (6) in Germany and Spain which presumably reflects their own satisfaction with the medicinal chemistry and chemistry content of their own pharmacy courses. A biochemistry qualification was consistently given a low rating (2–4). A qualification from another country (unspecified) was accepted but given a low rating (3–4) in France, Germany and the UK; other countries did not respond to this aspect of the question

These ratings indicated a preference, i.e. what was considered to be desirable, but did not always reflect the real background of the students actually in the courses, presumably because the most highly rated were not necessarily attracted to undertake a Ph.D. in medicinal chemistry.

In France, nearly 40% of the Ph.D. students reportedly recruited for a medicinal chemistry topic had a background in medicinal chemistry and there was a similar number in chemistry, whilst there were as many as 20% coming from biochemistry even though it was not as highly rated.

In Germany (59%) and Spain (69%) the highest numbers reported came from pharmacy, in accord with their ratings for this course, and the remainder were mainly chemists (25% and 33%, respectively).

In Italy the majority reported (55%) had a background of medicinal chemistry (and this had the highest rating of 7) reflecting the 'CTF' course.

In the UK and the USA chemistry was the main background reported (47%) and this also had the highest ratings, but a substantial number came from pharmacy (18% and 24%, respectively) even though they were rated less highly.

In this connection there appears to be a very big split between the schools of pharmacy and chemistry departments in the UK. Here, the ratings of backgrounds for Ph.D. entry showed a marked divergence. Three of the four chemistry departments responses gave very low rating to a pharmacy background (1–2), i.e. the least preferred. One may suppose that in these departments the research primarily involves chemical synthesis and/or studies of chemical mechanisms and that the respective professors seek students with the best available chemical background.

2.2.3. *The main focus of graduate student and postdoctoral studies*

It is of interest to see what aspects of medicinal chemistry were being researched in the universities, since this probably influences the future work of Ph.D. graduates and postdoctoral researchers (*table IV*). Except for Switzerland, the synthesis of biologically active compounds was reported to be a main occupation (21% in Japan up to 70% in Spain) and it was clearly dominant in Spain and the UK (63%). The focus of study must depend very much on the research interests of the medicinal

Table IV. Main focus of study for the currently enrolled postgraduate students and postdoctoral research assistants represented as percentages for each country.

Country	Number of postgrads + postdocs	Synthesis of biologically active compounds %	Structure–activity analysis %	Computer assisted drug design %	Bio-organic studies %	Enzyme studies %	Spectroscopic studies %	Drug anal. %	Other %
France	176[a]	30	30[h]	19	13	1	5.5	0.5	0.5
Germany	385[b]	48	26	13	8	11	7	12	8
Italy	98	44	15	6	4	0	1	3	3
Japan	162[c]	21	21[h]	3	12	13	6	13	12
Spain	142[d]	70	3	5	5	2	8	0	5[i]
Switzerland	51[e]	2	43	27	16	24	6	10	0
UK(A + B)	226[f]	63	17	7	14	4	4	4	2
USA	[g]								

[a] Includes 73 DEA students. [b] Some postgraduates are involved in more than one aspect of study. [c] This represents only a partial data set out of the total. [d] Includes masters students. [e] Includes 2 diploma (M.Sc. equivalent) students. [f] Includes 16 M.Sc. students. [g] Information not available. [h] Half of these involved physical organic studies relating to drug action.[i] Chiral separations.

chemistry professors and, presumably, on what can be funded. There was also a substantial interest in structure–activity analysis with some attention to computer-assisted drug design (CADD). In Switzerland, the synthesis of biologically active compounds in pharmacy faculties appeared to be almost non-existent and the emphasis was on structure–activity analysis, CADD, bioorganic and enzyme studies. In Germany, Japan, and Switzerland there appeared to also be an interest in drug analysis. Unfortunately such data were not available for the USA although an examination of faculty publications records indicates that synthesis and drug analysis primarily takes place in other departments.

2.2.4. The number of 'masters' and Ph.D. students graduated in the last 5 years

This question identified the output of students and should relate to the numbers currently studying unless there has been a big change. It is important to factor in the time spent by students on 'masters' and Ph.D. programmes. Thus, in France (*table V*), the DEA takes 1 year, and so the output from 5 years (334) should be approximately 5 times the current number (73), which it is. The Ph.D. degree takes 3–4 years, thus the current number of 79 represents about 20–26 per year, and a 5 year output should be 100–130; it is actually 90 which is a bit less than this level.

On the other hand the current number (24) of postdoctorals is similar to the past 5 years total (25); this is surprising and suggests that there has been a considerable recent increase in numbers, or that the 5 year number is not fully reported, or that the postdoctorals stay in their positions for several years.

Table V. The number of masters and Ph.D. students graduated in the last 5 years and the number of postdoctorals, where the primary focus was medicinal chemistry. The figures in parentheses indicate the number of postdoctorals whose Ph.D. degree was in organic chemistry (question 7).

Country	No. of replies	Masters	Ph.D.	Postdoctorals
France	16	334[b]	90	25 (22)
Germany	19		426	49 (5)
Italy	12		97	38 (2)
Japan	12	1 310[c]	[d]	65 (NA)[e]
Spain	6	49	72	32 (16)
Switzerland	3		55	16 (6)
UK	15	11	155	82 (71)
USA[a]	29	262	697	NA[e] (283)

[a] Numbers for the past 10 years. [b] DEA. [c] Includes Ph.D. graduates. [d] Included with masters. [e] Not available.

For the other 'master's' programmes we only have data from Spain and the UK and in each case the 5 year total was actually less than for the year of the questionnaire. This implies that the master's qualification has become more popular in these two countries. For the Ph.D. programmes, the 5 year total in the UK was approximately similar to the annual number, but for the other countries the totals were between 6 and 20% higher than the annual numbers, the highest being Germany and Italy. The 5 year totals for postdoctoral assistants were approximately 2.7 times the annual number for Japan, 2.4 times for Italy, 1.8 times for Spain, 1.6 times for the UK, and 1.4 times for Germany and approximately equal to the annual number for France and Switzerland. Without knowing the average duration of postdoctoral appointments one cannot sensibly comment further.

2.2.5. The present occupations (where known) of these Ph.D. graduates and postdoctorals

As might be anticipated, some of the Ph.D. graduates took up postdoctoral research positions. Expressed as percentages it can be seen (*table VI*) that this was relatively popular in France (24%) and the UK (30%), a bit less so in Germany (15.5%), Italy (18%), Spain (15%), and the USA (16%), and much less popular in Switzerland (9%) and Japan (2.5%). It is interesting to see that in France, Spain and Switzerland it appears that the students preferred to go abroad for their postdoctoral positions.

A substantial number of the Ph.D. graduates also took up academic or teaching positions, particularly in France (23%), Italy (33%), and the USA (52%). The percentages were lower in Spain (11%) and the UK (11%), and very low in Germany (5%), Japan (3%) and Switzerland (4%).

The type of occupation for the Ph.D. graduates showed a considerable variation. In France there was a preference for synthetic medicinal chemistry (11%). In Germany, the most popular were drug analysis (14%), drug registration or clinical research (11.5%), and pharmacy (6%), with very few entering synthetic medicinal chemistry (1.4%). In Italy, there were slight preferences for drug metabolism and pharmacokinetics (DMPK) (4%) and synthetic medicinal chemistry (4%). In Japan, the most popular were DMPK (7%) and synthetic medicinal chemistry (11%). In Spain, marketing or sales (12%) and synthetic medicinal chemistry (7%), and drug analysis (6%) were preferred. In Switzerland 7% went into drug registration or clinical research, but none went into synthetic medicinal chemistry. In the UK the preferred occupations were synthetic medicinal chemistry (19%), DMPK (5%), marketing or sales (5%), patents or information science (4%) and pharmacy (4%).

Table VI. The number of Ph.D. graduates and postdoctoral researchers for the past 5 years (where known) according to their present occupations, percentages in parentheses.

Country		Total number of postgraduates or postdoctorates	Entering industry	Postdoctoral research (home)	Postdoctoral research (abroad)	Academic/teaching	Drug analysis	DMPK	Patents or inf. science	Synthetic med. chem.	CADD	Drug registration or clinical research	Marketing or sales	Administration	Pharmacy	Production	Unknown
France	PG	90	21 (23)	5 (6)	16 (18)	21 (23)	2 (2)	0 (0)	0 (0)	10 (11)	2 (2)	2 (2)	0 (0)	0 (0)	0 (0)	0 (0)	6 (7)
	PD	25	8 (32)	2 (8)	3 (12)	12 (48)	0 (0)	0 (0)	0 (0)	9 (36)	3 (12)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	2 (8)
Germany	PG	426	195 (46)	49 (12)	17 (4)	21 (5)	59 (14)	7 (2)	15 (4)	6 (1)	8 (2)	49 (12)	9 (2)	2 (< 1)	27 (6)	0 (0)	
	PD	49	9 (18)	7 (14)	4 (8)	21 (43)	2 (4)	1 (2)	1(2)	3 (6)	0 (0)	2 (4)	0 (0)	0 (0)	0 (0)	0 (0)	18 (36)
Italy	PG	97	10 (10)	13 (13)	5 (5)	32 (33)	1 (1)	4 (4)	0 (0)	4 (4)	2 (2)	0 (0)	2 (2)	2 (2)	2 (2)	0 (0)	
	PD	38	9 (24)	13 (34)	5 (13)	8 (21)	2 (5)	0 (0)	0 (0)	7 (18)	0 (0)	0 (0)	0 (0)	0 (0)	1 (2)	0 (0)	
Japan	PG[a]	1 310[a]	917 (70)	11 (1)	18	35 (3)	38 (3)	91 (7)	14 (1)	147 (11)	37 (3)	46 (4)	31 (3)	0 (0)	0 (0)	0 (0)	38 (29)
	PD	65	32 (51)	0 (0)	7 (11)	18 (28)	3 (5)	5 (8)	2 (3)	18 (28)	3 (5)	4 (6)	0 (0)	0 (0)	0 (0)	0 (0)	4 (6)
Spain	PG	121	22 (18)	4 (3)	15 (12)	13 (11)	8 (6)	1 (1)	2 (2)	8 (7)	0 (0)	3 (3)	14 (12)	0 (0)	0 (0)	1 (1)	1 (1)
	PD	32	0 (0)	4 (12)	3 (9)	9 (27)	1 (3)	2 (6)	2 (6)	5 (15)	0 (0)	0 (0)	6 (19)	0 (0)	0 (0)	0 (0)	1 (3)
Switzerland	PG	55	21 (38)	0 (0)	5 (9)	2 (4)	1 (2)	1 (2)	2 (4)	0 (0)	2 (4)	4 (7)	2 (4)	2 (4)	2 (4)	0 (0)	33 (27)
	PD	16	0 (0)	1 (6)	1 (6)	7 (44)	0 (0)	0 (0)	0 (0)	0 (0)	2 (13)	0 (0)	1 (6)	0 (0)	0 (0)	1 (6)	3 (19)
UK	PG	166	54 (33)	28 (17)	21 (13)	18 (11)	4 (2)	9 (5)	6 (4)	31 (19)	1 (1)	3 (2)	9 (5)	2 (1)	6 (4)	0 (0)	32 (19)
	PD	82	25 (30)	17 (20)	10 (12)	11 (13)	0 (0)	2 (2)	1 (1)	14 (17)	1 (1)	0 (0)	0 (0)	4 (5)	2 (2)	0 (0)	3 (4)
USA	PG[b]	697	237 (34)	114 (16)		363 (52)											

[a] Includes M.Sc. students [b] Occupation of Ph.D. students graduated in the last 10 years. Occupation by activity not requested. Postdoctoral researchers not investigated.

Table VII. Courses attended by medicinal chemistry Ph.D. students.

Subject	France	Germany	Italy	Japan	Spain	Switzerland	UK	USA
Number of positive replies	6	18	5	8	6	2	13	29
	%	%	%	%	%	%	%	%
Bioassay	0	11	20	12	17	0	8	0
Biological chemistry	17	33	40	62	50	100	62	0
Combinatorial chemistry	33	11	20	12	17	50	31	55
Computer aided drug design	66	39	60	38	83	50	46	83
Molecular modelling	66	39	40	50	50	100	62	83
QSAR	33	39	60	12	67	50	69	76
Drug analysis	0	56	40	38	33	50	31	52
Drug metabolism	33	28	20	38	17	50	31	83
Enzymology	0	17	20	25	0	50	15	45
General lab. techniques	0	17	60	25	33	0	77	55
Molecular biology	17	11	40	50	17	100	38	52
NMR analysis	100	72	40	63	100	100	85	0
Organic synthesis	50	22	80	100	100	50	69	93
Special reagents	0	0	60	38	33	0	46	0
Patent law	0	6	0	12	17	0	8	7
Pharmacokinetics	17	44	40	50	0	50	23	41
Pharmacology	33	44	80	62	17	50	23	69
Physical-organic chemistry	33	11	0	88	17	50	31	79
Prodrugs	33	6	0	12	17	50	23	62
Radiochemistry	0	11	0	38	0	0	15	31
Separations technology	33	11	20	25	17	0	46	55
Spectroscopic methods	17	61	60	62	33	50	77	83
Statistics	33	17	20	12	17	0	46	0
Toxicology	17	17	20	38	0	50	15	38

This is a key question to identify the extent that industry is interested in the output from these teaching programmes. The numbers of Ph.D. graduates entering industry was very high in Japan (70% including masters). Elsewhere it varied between Germany (46%), Switzerland (38%), USA (34%), UK (33%), France (23%), Spain (18%), to Italy (10%).

The numbers of postdoctorals entering industry varied widely; the respective percentages were: France (32%), Germany (18%), Italy (24%), Japan (51%), Spain (0), Switzerland (0), UK (30%). For several of the countries, the main occupation taken up after postdoctoral research was an academic or teaching position. Thus expressed as a percentage these were: France (48%), Germany (43%), Italy (21%), Japan (28%), Spain (27%), Switzerland (44%), it was lower in UK (13%). However, a substantial proportion of the postdoctoral researchers continued into further postdoctoral positions, thus: France (20%), Germany (22%), Italy (47%), Japan (11%), Spain (22%), Switzerland (13%), UK (33%).

The type of occupation taken up by the postdoctoral researchers also varied considerably. Synthetic medicinal chemistry was popular in France (36%) and Japan (28%), but less so in Italy (18%), Spain (15%) and the UK (17%) and very low in Germany (6%) and non existent in Switzerland. In France and Switzerland, computer-aided drug design (CADD) was identified (12%); in Spain, marketing or sales was of particular interest (19%).

There are many job opportunities for medicinal chemists outside of academic teaching or synthetic medicinal chemistry. In addition to those jobs already mentioned, in most countries a few percent of postgraduates and postdoctorals go into drug analysis (1–6%), patents or information science (1–6%), drug registration or clinical research (2–7%), and marketing or sales (2–6%). A few medicinal chemists go into pharmacy or administration but they rarely go into production.

Thus it can be seen that the training of medicinal chemists equips them to enter a wide range of occupations. In some of the countries a substantial proportion of medicinal chemists do continue into synthetic medicinal chemistry. This is especially evident in France, Japan and UK. On the whole, the numbers entering industry also look reasonably healthy and contrast interestingly with the expressed preference for organic chemists received from those with responsibility for hiring in the industry.

2.2.6. Course work for Ph.D. students

It is most advantageous if students are formally assisted to develop their understanding of their subject whilst actively undertaking research. They are usually keen to delve further into details which strongly relate to their own research topic, but it is also useful to broaden their understanding and outlook, to prepare them for tackling varied problems in the future, and to reflect a diversity of future occupations. *Table VII* details the subject matter being taught.

The question was asked whether the Ph.D. students attend lecture courses and, if they do, respondents were requested to indicate which courses were taken by the medicinal chemists. They were asked to indicate the subjects taken according to a list provided (as given in *table VII*).

The number of replies to this question were particularly low from France (6), Italy (5) and Japan (8), perhaps indicating that it is not the general rule that graduate students have to attend lecture courses. Most encouragingly for the training of future synthetic medicinal chemists, the most popular courses involve core chemistry techniques such as organic synthesis, NMR analysis, and spectroscopic methods. Support was also generally provided by courses for structure–activity analysis, thus: computer-aided drug design, molecular modelling, and QSAR were generally indicated by over 40% of the repondents. However, the provision of physical-organic chemistry, on which these latter courses are based, was patchy. On the biological side, biological chemistry, pharmacology, pharmacokinetics and drug metabolism, were relatively popular.

2.2.7. Presentation skills for Ph.D. students

Communication in science is critically important and it is now generally recognized that it is extremely useful to help students to develop their presentation skills. The questionnaire asked: ‘Do your students have to develop their presentation skills, thus: to present a poster and/or seminar to the department, write a report apart from their thesis, present a communication to a scientific conference (if possible)?’. The results are in table *VIII*. The number of positive replies to each type of presentation skill is expressed as a percentage of the total number of replies received per country.

Giving a seminar appears to be more common than presenting a poster within the department or writing a report. It is good to see that students are generally encouraged to present a communication at a scientific conference and perhaps, these days, this usually involves a poster presentation.

Table VIII. Development of presentation skills for Ph.D. students. The number of positive replies to each subject given as a percentage of total number of replies per country.

Country	Number of replies	Present a poster %	Give a seminar %	Write a report %	Commun. scientific conference %
France	16	54	85	25	54
Germany	19	47	89	53	95
Italy	11	36	90	90	55
Japan	13	100	100	100	100
Spain	6	0	66	33	100
Switzerland	3	33	100	66	100
UK	15	60	87	93	93

2.3. The faculties

2.3.1. The number of academics involved in the education of postgraduate medicinal chemists

The numbers of academics reportedly involved in postgraduate medicinal chemistry teaching are given in *table IX*. There are substantial differences in the size of the various faculties or departments, ranging from 1–16 in Germany, 12–31 in Italy, 7–24 in Spain, 1–7 in Switzerland, 3–12 in the UK, and 2–18 in the USA.

The average number per department or faculty is: France, 7; Germany, 5.5; Italy, 19.6; Spain, 14.7; Switzerland, 3.3; UK, 7.7; USA, 7.5. Comparisons between countries have to be made with considerable caution because the same academics may, or may not, also be teaching undergraduates. Furthermore, some departments/faculties may use academics from other departments for teaching special subjects and this was not always evident from the answers provided.

2.3.2. The specialization by scientific subjects of the academics teaching postgraduate medicinal chemists (according to their highest academic degree)

It is very clear that synthetic organic chemists 20–52% (apart from Switzerland), and some physical-organic chemists 2–10%, as well as medicinal chemists 8–56%, are involved in teaching medicinal chemists and this suggests that a good organic chemistry basis is being provided (*table IX*). In addition, there are biochemists (1–20%), pharmacologists (0–11.5%), and others, including pharmacists.

For some countries (France, Germany and Italy) the answers added up to greater than 100% suggesting that some academics have at least two of the specialities identified, e.g. their highest degree, e.g. a Ph.D. could be combining synthetic chemistry with medicinal chemistry. For other countries (Spain, Switzerland, UK and USA)

Table IX. The numbers of academics involved in educating postgraduate medicinal chemists and their highest degrees.

Country	Numbers involved				Subject for highest degree						
	Total number	Number of replies	Average per department	Range per department	Synthetic chemistry	Medicinal chemistry	Physical organic	Biochemistry	Pharmacology	Pharmacy	Other
					%	%	%	%	%	%	%
France	112	16	7	NA[a]	43	39	9	6.5	11.5		3.5
Germany	87	16	5.5	1–16	21	56	2	1	4	21	
Italy	196	10	19.6	12–31	20	34	3	6	10	37	
Spain	88	6	14.7	7–24	52	8	3	2	6		5
Switzerland	10	3	3.3	1–7	0	30	10	20	0		10
UK	116	15	7.7	3–12	40	16	10	7	1		11
USA	216	29	7.5	2–18	28	31		15	4		

[a] Not available.

the answers totalled less than 100% (70–85%) suggesting omission of information.

2.3.3. Industrial experience or industrial consultancy of the academics teaching postgraduate medicinal chemists

Some of the academics have industrial experience, ranging from 6.5–10% in France, Germany, Spain, UK and US to 0–3% in Italy and Switzerland (*table X*). On average this implies that not every department/faculty has someone with industrial experience and this is rather unfortunate for an applied subject such as medicinal chemistry. On the other hand, higher numbers of academics act (or have acted during the previous 10 years) as consultants to industry ranging from 17–45% in France, Germany, Spain, Switzerland, and UK to 6% in Italy. This at least keeps them in touch with some of the needs and expectations of industrial research and development.

2.3.4. Number of academics possessing grants from external agencies in support of research

There is a wide variation between the countries in the extent to which academics have obtained research funding from external agencies. It is very high (70–80%) in Switzerland, UK and USA, suggesting that their work is well regarded by their grant judging peers, given the intense competition that exists for grant support. The numbers were much lower (14–25%) for France, Italy and Spain, and intermediate (39%) for Germany. This may suggest that in these countries there is less money available for research or that there are significant national differences in the structure of research funding.

It would be very interesting to analyse the nature of research funding for medicinal chemistry and the range of subject matter under study, but this would require much more detailed information than is currently available. Indeed, it could be the subject of a special investigation.

3. Discussion

The gulf between industry and academia as judged by these responses does not appear to be so wide. The impression given by the answers to the questionnaire sent to big pharmaceutical companies was that they were not particularly interested in hiring medicinal chemists. This must mean that their perceived needs for drug discovery

Table X. Academic faculty staff with industrial experience, industrial consultancies and/or grants from external agencies expressed as percentages.

Country	Industrial experience	Industrial consultant[a]	External grants
	%	%	%
France	6.5	17	14
Germany	9	28	39
Italy	3	6	21
Spain	10	16	25
Switzerland	0	> 40	80
UK	7	45	69
USA	10		70

[a] Currently and during the past 10 years.

are met by organic chemists. Presumably fewer medicinal chemists are required to select drug targets and to influence structure–activity analysis in comparison with the number of chemists needed for synthesis who may be working together in a team. In addition, a proportion of the organic chemists metamorphose into medicinal chemists by experience 'on the job' helped by short courses, eg. reference [8]. Furthermore, many more organic chemists than medicinal chemists are trained in universities, perhaps the ratio is >10:1. So it is easier for companies to find good organic chemists for drug synthesis, in comparison with the relatively few medicinal chemists available.

Big pharmaceutical companies, especially, organise drug discovery in teams of specialists and they seek the best specialists available. All these factors contribute to create the overall impression that big pharmaceutical companies do not especially seek medicinal chemists for drug discovery. This may not apply to the many small pharmaceutical companies engaged in drug research who do not have teams of specialists and who have to rely much more on generalists. The latter may be medicinal chemists who understand organic synthesis but at the same time know how to converse with biochemists, pharmacologists and other biologists. Possibly, this is where the many trained synthetic medicinal chemists find their employment. In any case, the evidence is that the academic training of medicinal chemists equips them to enter a wide range of occupations many of which are in industry. However, there are some noticeable national differences according to the country.

References

[1] The questionnaire was sent out in 1996 and 1997. Officers of the Section Committee were Dr N. Koga (President), Professor J.G. Topliss (Past President), Professor C.R. Ganellin (Vice-President), Dr J.-C. Muller (Secretary).

[2] Busse W.D., Ganellin C.R., in: Claasen V. (Ed.), Trends in Drug Research, Pharmacochemistry Library, vol. 20, Elsevier, Amsterdam, 1998, pp. 305–315.

[3] Ganellin C.R., Mitscher L.A., Topliss J.G., in: Annual Reports in Medicinal Chemistry vol. 30, Academic Press, New York, 1995 329–338.

[4] Busse W.D., Ganellin C.R., Mitscher L.A., Eur. J. Med. Chem. 31 (1996) 747–760.

[5] Members of the Working Party were C.R. Ganellin (Chairman), W.D. Busse (Bayer, Wuppertal, Germany), P. Lindberg (Astra, Hässle, Mölndal, Sweden), L.A. Mitscher (University of Kansas, USA), G. Tarzia (University of Urbino, Italy), and C.G. Wermuth (Université Louis-Pasteur, Strasbourg, France); see also the footnotes to *table I.*

[6] Ganellin C.R., Mitscher L.A., Topliss J.G., Med. Res. Rev. 18 (1998) 121–137.

[7] Kobayashi T.-H., Ganellin C.R., Medchem. News 8 (1998) 21–28.

[8] Ganellin C.R., Syllabus for a Short Postgraduate Course in Medicinal Chemistry, Chemistry International 17, Blackwell Science, Oxford, 1995, pp. 212–214.