# Standards for the Ph D Degree in Biochemistry and Molecular Biology

## Recommendations of the Committee on Education of the International Union of Biochemistry

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**Rationale**

During the twentieth century the preparation of students to conduct research in Biochemistry and Molecular Biology has grown from a small beginning to a major industry, producing about 1000 PhDs per year. During the early decades those few active investigators who were responsible for the growth of the field comprised a brotherhood of individuals well informed about each other's activities and aware of the status of research throughout the biochemical world. At that time the instruments and techniques were relatively simple, the rate of change in the field was slow and the judgments of the established investigators about advancing their apprentices to independence were generally similar. However, as a result of explosive growth and fragmentation into subspecialties, the thousands of scientists qualified to supervise professional training in biochemistry and molecular biology now comprise a heterogeneous group, and the informal methods of the past no longer serve to maintain similar standards among nations or even among institutions within a country.

Biochemistry and the related disciplines which apply chemical and physical methods and principles to the solution of biological problems are among the most vigorous and productive areas of scientific development. However, while a large number of investigators have continued to develop the intellectual and experimental aspects of these sciences there is evidence that many holders of a PhD degree are incapable of contributing to scientific progress or of applying science to practical problems. The profession must recognize changes in itself and its environment so as to adapt and to prevent deterioration. Although progress in scientific knowledge and understanding does not come equally from all members of the profession, most of society accepts that one PhD is the equivalent of another. There are established departments that do not contribute significantly to the international literature but that award PhD degrees. Differences in competence of individuals appointed as postdoctoral fellows or junior faculty members have been known to result in prejudice against individual departments or even against entire countries. The differences are great enough to indicate that the quality of the profession may be jeopardized if no action is taken to formulate and to maintain standards.

Among the reasons for the differences in professional training is the diversity of educational systems in various countries that prepare students in very different ways to enter professional study. However, the end result should be the same, regardless of the methods used: *a holder of a PhD in Biochemistry should have the knowledge, skills, perspectives and understanding to be capable of independent scientific work of a quality satisfactory to others in the field.*

Science depends upon integrity. One of the functions of editors of scientific journals is the elimination of imprecise statements before publication so that other investigators can repeat

published experiments without difficulty. In general, there is little purpose in duplication of effort and most research is based on the results obtained by others. Scientists often disagree about interpretations but the accuracy of reporting of methods and of results of measurements is not questioned except in rare cases when aberrant behavior is suspected. Well publicized examples of publications that contain false results are evidence of the effectiveness of the self-correcting mechanisms of the scientific system. However, every instance of dishonesty, no matter how trivial it may seem, has the potential to be very harmful to individual scientists and to the relationship between science and the rest of society. Because of this, all students must be trained in an atmosphere of unquestioned integrity and any act of deliberate distortion or misrepresentation should be considered by the appropriate administrative authorities as grounds for dismissal or a severe warning with monitoring to ensure compliance with ethical standards. It is to be assumed that every department or laboratory engaged in the pursuit of scientific knowledge is characterized by an atmosphere of mutual trust and that unethical behavior will occur so rarely that procedures designed specifically to detect it would be counterproductive.

As Biochemistry and Molecular Biology develop even faster and as the potential for material rewards increases, competition for priority becomes keener. One danger is that this may lead to misrepresentation of data and the omission of reference to related or similar published work. Science remains, nevertheless, a collaborative effort and graduate education must emphasize the interdependence of scientists upon each other and the feeling of participation in the work of an international community of trustworthy scholars. It is assumed that those who wish to join this community must accept the ethical precepts that have characterized science.

The experiences that have brought illustrious investigators into the biochemical sciences have been so varied that it would be presumptuous to try to design an ideal program of education. Further, in a field that is still evolving rapidly, scientists looking to the future must not be fettered by restrictions imposed by others. Therefore, this document does not prescribe procedures to be followed. Instead, it describes behavioral abilities that should be characteristic of those awarded a PhD degree, suggests how these abilities may be acquired and some methods by which progress toward attaining the abilities may be assessed, and proposes criteria for the overall evaluation of candidates for the degree. These guidelines are intended as an aid to university departments, to national organizations that set standards for graduate education, to those scientists who serve as external examiners to evaluate theses, and to candidates for graduate degrees.

## Guidelines for the PhD Degree in Biochemistry and Molecular Biology

The purpose of a PhD program is to train independent, reliable, and competent research scientists. Although many holders of PhD degrees find employment that does not involve research, the degree implies that an individual has demonstrated an ability to pursue a research problem to a meaningful conclusion. The research experience obtained in acquiring the PhD degree should assure that the awardee understands and accepts the values of scientific research and is capable of using professional standards in all professional activities, ie teaching, practical applications or administration, as well as research.

Biochemistry and Molecular Biology are experimental sciences. However, the PhD candidate should not be trained as a technician. The training of every student should be sufficiently varied so as to give a theoretical understanding of the major techniques in current

usage and should include enough practical experience to encourage the use of any methods that might contribute to the solution of problems. However, specialization of productive investigators and collaborations within research teams and between established scientists in different institutions should be recognized as characteristic of present day research. Therefore, the training of students in laboratory techniques not directly involved in their own research should be restrained so that acquisition of extensive technical competence is not exaggerated to the detriment of other essential skills.

**Standards**

*(1) The candidate should demonstrate a general knowledge of Biochemistry and Molecular Biology and a detailed knowledge of the topics related to the area of research*

The knowledge of the discipline acquired by a candidate for the PhD degree should go beyond the level of comprehension attained at an undergraduate level where frequently the broad principles and the terminology of the discipline based on recall of textbook information are sufficient to satisfy examination requirements. It should be at a professional level, ie, based on an understanding of the experimental method(s) from which some of the basic principles of the science have been derived, rather than on the conclusions that others have derived from the use of these methods. This implies the reading and analysis of some of the original publications in some areas, and of review-type papers such as are published in *Advances in Enzymology*, *Trends in Biochemical Sciences*, *BioEssays*, *Cells*, *Annual Reviews of Biochemistry*, *Nature* and *Science*. Such a knowledge of Biochemistry and Molecular Biology implies familiarity with the structures and properties of common biomolecules, major metabolic pathways, principles of regulation of biological phenomena, the organization and function of subcellular structures and organelles, genetic expression, structure and replication, and the experimental basis for some of the current beliefs and models in the particular area of research. Professional knowledge should be attained by the time the candidate is awarded the PhD degree. Since the extent to which such knowledge is acquired during undergraduate education varies, the supplementary education during the PhD training period must be adjusted according to the need.

Attainment of appropriate insights can be evaluated formally (by essay writing, comprehensive oral tests, etc), or informally (by questioning on matters relating to the research proposal, during periodic review of progress, during seminars or journal-club presentations made by the candidate, during review of early drafts of the candidate's thesis). Although evaluation is likely to be mainly the supervisor's responsibility, it could also be the shared responsibility of the candidate's supervisory committee and the supervisor.

*(2) The candidate should be familiar with the literature of Biochemistry and Molecular Biology and should have the ability to keep abreast of major developments and to acquire a working background in any area*

The scientific literature is the lifeblood of the growth and development of a discipline. It contains not only the results of investigations conducted by established scientists, but also their reasoning, experimental strategies, descriptions of technique and materials, discussion of results and evaluation of hypotheses, and the models of processes and phenomena which summarize much of the accumulated wisdom of the discipline. Familiarity with the literature identifies areas that have already been explored or which requires exploration, and those where available results or interpretations are still

controversial. The literature is the major link between biochemists throughout the world and is the repository of a vast amount of scientific information. This is the same literature to which the candidates are being prepared to contribute during their training and in the future. The abilities to review the literature, to evaluate it critically, to abstract from it the useful and the valid as a basis for further exploration or investigation, are essential for an independent biochemist.

Avenues for the development and evaluation of these abilities include: the preparation of the research proposal, seminar and journal-club type presentations, preparation of results for publication, periodic review of progress, preparation of the thesis, preparation of a proposal for a research grant, etc.

*(3) The candidate should possess technical skill in laboratory manipulation*

Since the number of experimental techniques is very large, a doctoral candidate cannot acquire formal training in every available technology. Rather, the candidate should be expected to have acquired enough technical skill to be able to function in the research for which the degree is to be awarded. The candidate should demonstrate capability in the laboratory techniques related to the research project, a good understanding of the theoretical basis for these techniques and sufficient self-confidence and competence in laboratory methodology so as not to be inhibited in adopting such new technology as may be required for the carrying out of research in future. Technical competence and flexibility are essential tools for independent research.

Avenues for development of this ability include the carrying out of the experimentation for the thesis, specially designed laboratory courses, or short periods of training in other laboratories.

*(4) The candidate should demonstrate skill in the recognition of meaningful questions for investigation in Biochemistry and Molecular Biology*

This ability arises in part from familiarity with and critical evaluation of the general literature of Biochemistry and Molecular Biology. It requires broad knowledge, creativity, and imagination and is facilitated by discussion with other scientists. Meaningful questions are circumscribed, solvable ones whose answers become part of accepted scientific knowledge and contribute to the basis for further research. Alternatively, meaningful questions are those of interest to others working in related areas.

The ability to evaluate questions is developed by responding to questions raised by the supervisor within an educational setting, analysis of questions asked in published papers or scientific seminars, the raising of questions on the basis of results in specific papers and seminars, the drafting and defence of research proposals, periodic review of the doctoral research, and preparation of the thesis.

The candidate should have access to structured experiences whose major objectives are to provide opportunities to present and defend research plans and their results and interpretations, to evaluate and comment on the work of others, and to participate in discussions about technical and scientific issues.

Acquisition of the ability to recognize meaningful questions is a major step in the candidate's transition from a passive to an active role in Biochemistry and Molecular Biology. One way of evaluating this skill is to require a candidate to make an oral presentation, after a brief preparation time, on a topic unrelated to that of the thesis. The candidate could be required also to identify questions from this topic that deserve further study and to present and discuss possible experimental approaches that might be used to obtain answers to such

questions.

*(5) The candidate should demonstrate that oral and written communication skills have been acquired*

Scientific research is of very limited value until its results and their interpretation are made available to the scientific community. Scientists communicate by giving lectures and seminars, by posters, by periodic reports on their research, by applications for grant money, by writing up of material for publication. Communication skills are learned through practice and through acquisition of confidence in latent abilities. They need not be taught through formal courses during the doctoral process, but should form an integral part of the process. There are many opportunities during the doctoral process for their development eg, in the preparation of the research proposal, the periodic review of research progress, the preparation and oral defense of the thesis, preparation of research material for publication, journal-club presentations and seminars, etc. Opportunities should also be taken for discussion of ethical aspects in the presentation of results, and in the attribution of credit for the work of others, including appropriate reference to published work.

It is the responsibility of the supervisor or of the department or institute where the candidate is to work to indicate to the candidate at the beginning of the doctoral training what is expected and to provide positive feedback and guidance at every opportunity.

*(6) The candidate should demonstrate skill in designing experimental protocols and in conducting productive independent research*

This skill is of fundamental importance for an independent biochemist. Its acquisition is demonstrated by the successful completion of a self-initiated piece of research that leads to publication in an international refereed journal. This involves the asking of questions at an appropriate level (not too trivial, not too large), the carrying out of appropriate experiments with suitable controls, statistical treatment and analysis of the results, deriving of answers (ie, conclusions) to the questions posed, and their acceptance by the scientific community by refereed publication.

This skill is not acquired simply by the collection or compilation of data, by cataloguing of observations or by other activities in which the candidate serves as a technician. The candidate must participate actively in the selection of the problem. Supervisors should assist in orienting their candidates to the relevant literature but should not impose their will on the students. The supervisor and the supervisory committee should participate in periodic evaluation of the progress in a critical way but should permit the student to carry out independently

planned experiments and even to learn from mistakes (within reasonable limits set by budgetary and safety considerations).

The original descriptions of the thesis problem should not be too restrictive. The candidate should be encouraged to recognize leads suggested by results and be permitted to change the problem if the change appears likely to produce more meaningful results. The balance between persistence in overcoming difficulties and wasting time on poor ideas must be learned by experience. Similarly, the lure of tempting new ideas must be resisted to the extent needed to bring projects to publishable conclusions.

The role of the supervisor in directing student research is one that requires subtle adjustments. In general, candidates begin with little relevant knowledge, restricted skills and limited perspective and require a considerable amount of guidance. However, the naive beginner must evolve into an independent investigator during the thesis work. The development of skills and independence are acquired only through practice. The supervisor must decrease detailed directions as the project proceeds and may have to accept a loss in efficiency in the work of the laboratory as part of the cost of professional education. The supervisor and the candidate thus become colleagues participating in a joint research project.

The supervisor and the candidate participate as partners in a mutual effort but not as equals. Since the process of doctoral training contains a major element of apprenticeship the supervisor is not only teacher but is also a major determinant of the relationship of the candidate to the scientific community and of his subsequent professional opportunities.

**Role of Formal Graduate Courses**

Formal courses are a convenient route to the acquisition of information in a field of study. They are frequently used to expand the general information base of students. Since the primary goal of graduate training is the acquisition of independence and familiarity with the pertinent literature, formal courses are useful to the graduate program only if they permit the student to become competent in acquiring knowledge independently and if the acquisition of information is not used as the dominant measure of the student's development. Graduate level courses should therefore facilitate the student's use of literature and be concerned with the student's active self-education. Since the independent scientist needs to keep up with developments in the field, any required graduate courses should be directed toward this future need.

Graduate courses in Biochemistry and Molecular Biology should be designed to produce better scientists. They should be designed to develop permanent intellectual skills rather than the accumulation of transient, memory-based information and should contribute to the development of a professional attitude. Regardless of course content or format, accumulation of credits by 'passing' courses does not provide evidence that the candidate is better prepared to contribute to science.

It must be appreciated that courses may be time-consuming and can be disruptive of experimental work, and that the knowledge and skills that they may foster can be acquired in other ways (eg, .journal club activities, reviews of the literature on selected topics, seminars on topics unrelated to the research, etc).

**Role of Academics Other Than the Supervisor**

Though the doctoral process is often viewed as being based largely on the supervisor-candidate relationship, the complete training of the candidate to meet these standards may be, and very frequently is, beyond the ability of the supervisor. Since few, if any, supervisors are completely self-sufficient, it must be recognized that other academics and doctoral candidates

have an important role in a candidate's training. This not only broadens the scope of the learning environment for the candidate, but also demonstrates the social and interactive nature of scientific research.

It is the role of the department or institute in which the candidate is being trained to provide the environment in which the skills and competencies outlined in the section on standards can be acquired and to help identify others besides the supervisor who should participate in the training of the candidate.

**Duration of Doctoral Training**

The transition from student to professional does not proceed at the same rate for different individuals. An even greater variable is the period for completion of various research projects. It is not reasonable to expect that the requirements for a PhD degree can be completed within a short period of time. Where outside forces (usually governmental ones) apply economic pressures to restrict the time for graduate training, members of the profession should resist these pressures to award degrees prematurely or to reject students who could become useful professionals given longer periods of training. The awarding of a PhD degree should identify an individual who has acquired high standards of scientific research and who does not compromise those standards to meet arbitrary deadlines.

Since the candidate is expected to acquire or develop a professional philosophy and professional values in addition to technical knowledge and skills, regardless of success in research, the period of training should not be less than three years.

The progress of every candidate should be monitored by a supervisory committee. Decisions about abandoning unproductive projects should not come suddenly after several years, but should arise from discussions with the candidate while there is still time to complete the degree within the conventional period. Serious questions must be asked early in the training process about the abilities of the candidate to complete the type of work which will lead to a satisfactory thesis within a reasonable time but arbitrary time limits should not be inflexible.

**The Doctoral Thesis**

The doctoral thesis is the ultimate tool for evaluating the acquisition of skills and abilities required for certification of a candidate as a competent, independent scientist. It must serve not only to ascertain that the student has participated in successful, meaningful research but also that the student's contributions have been significant.

The doctoral thesis may take different forms. At one extreme, it may be a lengthy document giving a thorough review of the literature, an explanation of the problem(s) selected, detailed descriptions of the methods, a complete presentation of experimental results and a long discussion of the interpretation and implication of the findings. At the other extreme, it may be one or more published papers. Since it is not possible to evaluate the student's contribution to any formal publications, especially when there are other authors and since journals restrict the amount of explanatory and interpretative material, the thesis should include material written by the candidate to supply information beyond that included in published papers. It should show clearly that the candidate has put the research into scientific perspective and that the student's contributions to the research are differentiated from those of other contributors. Such material should introduce each publication used as part of the thesis and there should also be a general discussion that establishes the significance of the research and its implications for future investigations or application.

The size or volume of thesis material should not be used as a criterion in its evaluation.

Prior publication of material to be included in a thesis should be encouraged. The rapid pace of scientific development requires that all meaningful research be published as rapidly as possible. The PhD degree should only be awarded for a thesis which contains original work which has already been published or which is deemed suitable by the examining body for publication in an established, refereed journal in the field.

### Concluding Remarks

Experience in various institutions and countries has shown that competent biochemists can be produced by diverse systems, ranging from the highly structured to the almost completely unstructured. Because of the frequent necessity for external review, however, it is essential that all departments or institutions in which training for the doctoral degree is undertaken develop instruments for evaluating the competence of their candidates and establish procedures for developing all of the professional skills characteristic of successful investigators before the PhD is conferred. ■

The writing group consisted of: L Joseffson, A Mehler, F Vella and E J Wood. Grateful acknowledgement is made to the following who commented on earlier drafts of this document: the Executive Committee of IUB, the Professional and Educational Committee of the Biochemical Society (UK), M Akhtar (Southampton, UK), J F Angel (Saskatoon, Canada), T Blundell (London, England) K E Ebner (Kansas City, USA), W H Elliott (Adelaide, Australia), T Murachi (Kyoto, Japan), W Rombauts (leuven, Belgium)., J D Wood (Saskatoon, Canada).