Standards for Doctoral Degrees in the Molecular Biosciences

Recommendations
of the Committee on Education
of The International Union of Biochemistry
and Molecular Biology

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I. Foreword

Biological Science has been changing at a stunning pace with unprecedented growth, a deepening of knowledge and proliferation of methods of investigation. At this time interdisciplinarity has become commonplace and even essential as the barriers among the traditional biosciences disappear. Biochemistry and molecular biology, cell biology, structural biology, developmental biology, genetics, immunology, microbiology, neurobiology, nutrition, physiology, pharmacology, and molecular medicine now speak the same scientific language and use the same molecular tools. It is not unusual for elements of these molecular biosciences to be combined in a single degree. In addition, informational science has made possible the birth of genomics, proteomics and bioinformatics, while interest has been moving from molecules to mechanisms and to whole organisms, from a focus on individual components to biological systems.

In 1989 the Committee on Education of the International Union of Biochemistry published its Standards for the Ph.D. Degree in Biochemistry and Molecular Biology. These received wide approval as being sound and quite generic by virtue of being expressed in behavioral terms. In 2000 a modified and updated version of those Recommendations was published that was more generic and broader in scope by addressing not only Biochemistry and Molecular Biology but all the Molecular Biosciences. A small writing group was appointed to update the 2000 Recommendations. This group has been charged with producing a draft report to be submitted for comment to an international panel of bioscientists before being presented for publication on the Union's website. The majority of those on this panel were not involved in the previous Recommendations. Some continuity with previous Recommendations was provided by the chair of those serving as a member of the present writing group.

We thank the Executive Committee of IUBMB for their valuable assistance and support, the Committee on Education for participating in this project, all those who contributed with their comments and other suggestions, and all those who contributed to the previous Recommendations for providing a basis for the ones here presented and

for facilitating our work. Final responsibility for the contents of the present Recommendations, however, rests equally with those named below.

George Kenyon (Chair)
Susan Hamilton
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Adele Wolfson

II. Further Background

During the twentieth century the preparation of students to conduct research in the Molecular Biosciences grew from a small beginning to a major industry. At first the small number of investigators who were responsible for the growth of the various fields comprised a community of individuals informed about each other's activities and aware of the status of research throughout the bioscience world. Instruments and techniques were relatively simple, the rate of change in the various fields was relatively 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 the Molecular Biosciences now comprise a heterogeneous group, and the informal methods of the past do not permit similar standards among nations, within a country, or even within the same institution.

The Molecular Biosciences that apply chemical, physical, and molecular biological methods and principles and the laboratory methods of Biochemistry and Molecular Biology to the solution of biological problems (including those of biomedical and agricultural importance) have become multidisciplinary, reliant on computer power, systems-oriented, and quantitative. They are among the most vigorous and productive areas of scientific development. The profession must recognize changes in itself and in its environment so as to adapt and to meet better the challenges of a fast-changing world. Although progress in scientific knowledge and understanding does not come equally from all members of the profession, most of society accepts that degrees awarded by different universities are essentially equivalent. Departments in which the research capability is low are encouraged to network with one or more of higher capability so as to be able to offer their students a more valuable education. Similarly, formal courses should not be a substitute for a significant research program.

The Doctoral (Ph.D. or D. Phil) degree is the crown of an individual's academic preparation for worthy scholarship. It acknowledges the satisfactory completion of at least 2 to 5 years in full-time research on a particular problem which produced results worthy of, or accepted for, publication in a peer-reviewed journal. For over half a century it has been the basic academic qualification for employment in academia, indicating that the candidate is knowledgeable, can speak authoritatively on that topic of the individual’s research and on closely related fields, and is capable of further, largely independent, research. However, employment opportunities also exist outside academia that also make use of the acquired transferable knowledge and skills. Because of the speed at which the molecular biosciences have been developing, it is not unusual for a recently-graduated Doctor to undertake one or more periods of postdoctoral fellowship. The aim of this usually is to produce publishable results by working mostly independently on a different project which may involve different laboratory techniques. This increases the individual's overall knowledge and laboratory skill, confidence and independence as a scientist. Since this does not lead to a university degree, it will not be discussed further here. Similarly, the D.Sc. degree does not fall within the scope of these guidelines.

The experiences that have brought illustrious investigators into the biomolecular sciences have been so varied that it would be presumptuous to try to design an ideal program of education and training. Further, in fields that are still evolving rapidly, scientists looking to the future must not be fettered by restrictions imposed by others. Therefore, rather than prescribing procedures to be followed, these Standards emphasize abilities that should be characteristic of those awarded a doctor’s degree in a Molecular Bioscience, suggest how these abilities may be acquired and how their attainment may be assessed, and propose criteria for the overall evaluation of candidates. They are intended as an aid to university departments and boards of graduate studies, to national organizations that set standards for graduate education, to those scientists who serve as external examiners to evaluate theses, and to candidates for a degree in these sciences.

This revision comes at a time of strong competition in research and increased industrial sponsorship of academic research, forces that place emphasis on the rapid publication of results, on the development of practical applications, and on confidentiality. These have decreased the control over preparation of candidates especially at the higher level by academic and publicly-funded research institutions whose very existence is predicated on the production and transfer of knowledge. These Standards are intended to emphasize quality in the preparation of graduates for scholarship or for other productive careers and to deemphasize over-specialization.

III. Doctoral Degrees in the Molecular Biosciences

The purpose of any doctoral degree, but particularly in a Bioscience, is to educate and train competent, reliable, and self-directed, individuals who have a strong sense of scientific integrity. Such a degree implies that the graduate has demonstrated the ability to pursue a problem to a meaningful conclusion. For a Doctoral degree, the research problem is a substantial one, broader in scope and depth than for masters or bachelor's degrees that constitute a significant contribution to advancement of basic or applied knowledge. It comes with an ability to use professional standards, e.g., in teaching, publication in the peer-reviewed literature, practical applications, project management or administration, relations with industrial sponsors and research.

The academic component of a doctoral degree should include a good theoretical understanding of the major techniques in current usage and should include enough practical experience to ensure confidence in the use of novel methods as may be necessary. It should include components that require interaction and collaboration between candidates in group projects in preparation for making effective contributions within the multidisciplinary teams that are characteristic of modern scientific research and of most areas of employment. In an era of enormous and rapid accumulation of facts and observations in the Molecular Biosciences and other aspects of the living world and rapid changes in techniques, it must be emphasized that it is the interaction between observation, experiment and theory that is fundamental to all science. Candidates should have opportunities to practice looking at problems from different perspectives and applying integrative thinking.

IV. Standards

1. The candidate should demonstrate a general knowledge of physics, organic and physical chemistry, mathematics (including calculus, probability and statistics), computer science, biology and cell biology, genetics, biochemistry and molecular biology, bioinformatics, the particular Molecular Bioscience, and good knowledge of the topic of research.

Knowledge of a Bioscience implies familiarity with: the structure, properties and functions, biosynthesis and degradation of major biomolecules; the ultrastructure of cells, organs and tissues; the major metabolic pathways; the principles of regulation of biological phenomena; cell signalling; the molecular biology of genomes, gene structure, expression and replication; biological defense systems; an understanding of the molecular phenomena that integrate organs and systems within an organism; international databases; knowledge of the literature on and around the research topic and the experimental basis for some of the current canonical knowledge, paradigms and models in the particular area of research. Knowledge of informatics, acquisition of a background of the "omic" sciences, use of internet and access to the scientific literature via this medium, use of CD-ROM databases, and data processing are essential. It is also important for the student to learn how to design a "high-throughput" experiment and to develop interdisciplinary skills. Some understanding of the organization of the profession and an appreciation of the historical development of the particular Bioscience should also be attained.

It is nearly impossible to function in the modern scientific community without a working knowledge of English. Over 90% of the published scientific literature is in English. This is the language of most of the internet and of most international congresses and conferences. Admission of candidates into degree programs in the English-speaking world from countries where English is not the spoken language requires demonstration of competence in speaking and writing this language by satisfactory completion of the Test of English as a Foreign Language (TOEFL) or an equivalent.

2. The candidate should be familiar with the research literature of the particular Bioscience should have the ability to keep abreast of major developments and to acquire a working background in any area.

The literature of a Bioscience contains not only the results of investigations conducted by established scientists, but also their reasoning, experimental strategies, descriptions of techniques and of materials, discussion of results and evaluation of hypotheses. It also contains the models of processes and phenomena that summarize much of the accumulated wisdom of that discipline. Familiarity with this literature means identifying areas that have already been explored or which require exploration and those where the results or interpretations that are available are still controversial. The literature is the major link between bioscientists throughout the world and is the repository of a vast and increasing amount of information.

The abilities to access and review the literature of a Bioscience, to evaluate critically in a publication the experimental design and results and if necessary to make statistical inferences, to abstract from it the useful and the valid as a basis for further exploration, and to communicate its content effectively, are not only essential for work in that discipline but are also easily transferable to many other professions.

The doctoral candidate should demonstrate the skills of definition and formulation of a research problem and possible ways to solve it. These require effective information retrieval, information processing, and analytical and critical evaluation of information. Avenues for development and evaluation of these abilities include: preparation of proposals for research and for grants, regular scanning of several journals to maintain a general view of the Molecular Biosciences, seminar and journal club presentations in the area of the research as well as outside it, preparation of results for publication, periodic and critical review of the candidate's work and progress, and preparation of the thesis. Acceptance for publication of results obtained during the research project indicates the candidate's potential for further contribution to the literature.

Some involvement in undergraduate teaching (e.g., as a teaching assistant, tutor, or laboratory demonstrator) is recommended as it encourages and sustains a breadth of interest beyond the thesis topic, develops instructional skills, and encourages consideration of teaching as a career option. Indeed, some programs within the Biosciences include such a teaching experience.

3. The candidate should demonstrate skill in the recognition of meaningful problems and questions for research in the particular Bioscience.

This ability arises in part from familiarity with and critical examination of the literature in that Bioscience. It requires broad and detailed knowledge, creativity and imagination, and is facilitated by discussions with other scientists. Meaningful problems and questions are circumscribed and solvable by rigorous experimentation, and often require the use of new technical skills. Answers to them become part of the accepted knowledge and contribute as the basis for further research.

Candidates should have opportunities to present and defend their research plans, to discuss their results and interpretations, to evaluate and comment on the work of others, and to participate in discussions on technical and scientific issues. Active participation in research seminars and attendance at local, national or international meetings should be encouraged. In this way candidates can establish networks, engage in scientific discussion, expand their horizons and acquire skills necessary for further collaborative work.

4. The candidate should possess technical skill in the laboratory, including computational and mathematical manipulations.

The multiplicity of experimental techniques means that candidates cannot be trained formally in all but a few basic ones of Biochemistry and Molecular Biology and of the particular Bioscience. In these, and in informatics and mathematical manipulations, candidates should acquire sufficient competence to function efficiently and reliably especially in the associated research project. They should understand the principles on which the necessary apparatus is constructed and of quality control and should have the self-confidence not to be inhibited in adopting unfamiliar technology as may be required. As the use of commercial kits has become commonplace, candidates should understand the theoretical basis of those that they use, their components and their advantages and disadvantages.

The research infrastructure in different countries, and even in universities within a country, is highly variable. Through specialized laboratory courses or workshops and cooperative research, inter-institutional programs can enhance the capability of universities that are less endowed and can help remedy this situation. Such programs are more likely to be available when faculty have well-established professional networks into which candidates can be introduced.

Candidates for graduate degrees should be aware of and should adhere to current standard operating procedures and to principles of good laboratory practice as they affect human experimentation, use of animals in teaching and research, laboratory safety, use of potentially dangerous substances, and radioactive materials, to the current code of ethics (see IUBMB Code of Ethics), and, if appropriate, the use of recombinant DNA technology including transgenic species.

Candidates' competency in laboratory techniques used in their research should have made them confident in exploring and learning any novel technique that may be required for further scientific work. They should be knowledgeable on good laboratory practices and standard operating procedures of the institution in which they perform the research.

5. The candidate should demonstrate the acquisition of oral, written and visual communication skills.

The value of scientific research depends on the effective dissemination of results and of their interpretation to the scientific community. Scientific communications include lectures, seminars, formal oral presentations at meetings, attractive and informative posters, published manuscripts, applications for research support, presentations to non-scientists and web sites. Communication skills in science place a premium on logical argumentation and clarity of speech, and on writing with persuasiveness and consistency. They are acquired through practice, and over time candidates develop confidence through feedback received. Candidates should have access to specific short courses or workshops on public speaking, poster preparation, use of communications media, and effective writing. Every opportunity should be taken for discussion of ethical matters regarding presentation and publication of research results, consultation with contributors to research, rigorous attribution of credit for the work and materials provided by others, delineation of their role in any publication, and handling of conflict of interest. The whole education of candidates should emphasize and integrate these skills which are largely generic and transferable to any career path that may be chosen.

Candidates for graduate degrees should have some experience of mentoring, management skills (including basic concepts of grants and of time management) and some teaching skills. Candidates should also present seminars outside their research topic, make oral poster presentations on their research at society or other meetings, and prepare manuscripts for publication of research results. They should be fluent in using communications media.

6. The candidate should demonstrate skill in designing experiments and in conducting productive self-directed research.

Collection or compilation of data, cataloguing of observations, or other activities in which a candidate serves as a technician foster dependency rather than encouraging self-directed research. Successful completion of a self-initiated piece of research involves: asking of questions at an appropriate level, devising and conducting appropriate and reproducible experiments with suitable controls and good quality-assurance, statistical analysis and treatment of results, deriving of answers to the questions that have been asked, and their acceptance of these answers by the scientific community, especially in a refereed publication, if at all possible.

This contributes to the growth and scope of the particular Bioscience. Candidates should participate actively in selection of the problem. The supervisor should orient the candidate to the relevant literature, provide advice on costs and likely duration of an experiment, on possible risks and on the extent to which commercial reagents and materials obtained from other sources can be relied upon, and make periodic evaluation of the candidate's progress. A critical approach to all aspects and an awareness of the need for appropriate controls are essential.

The original description of the doctoral thesis problem should not be too restrictive. If early results provide promising leads, the candidate should propose experiments based on these results and be permitted to change the problem if it is likely to produce more valuable results. However, the lure of new ideas later in the program may have to be resisted in the light of the time constraints that are set by tenure of scholarships and governmental or institutional regulations. The scope should be such that two peer-reviewed publications should be expected from the experimental work. A written report, followed by oral presentation and defense, at the end of the first year (of three) or second year (of four), should be used to determine whether the work is likely to be productive enough to lead to an acceptable thesis and to assess whether the candidate has the intellectual and technical abilities to succeed and the willingness to do the necessary work.

V. Integrity in Science

A fundamental cornerstone of science is the personal integrity of the scientist; without integrity the enterprise collapses. Results published in scientific journals or presented at meetings should represent honest accounts of the work done. Two major functions of editors of scientific journals have been to provide an independent peer review system for articles submitted for publication, and to eliminate inaccurate and imprecise statements before publication, so that the published experiments can be repeated without undue difficulty. Recent years, however, have seen high-profile cases of retraction of articles because of compelling evidence that they contained fabricated data.

The small number of such well-publicized examples is evidence of the effectiveness of the self-correcting mechanisms of the scientific system. 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 candidates must be educated and trained in an atmosphere of unquestioned integrity, and any act of plagiarism, deliberate distortion, misrepresentation, and misleading ascription of authorship or unrevealed conflict of interest 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, fairness, scientific honesty, and openness. Nevertheless, universities should have procedures in place to deal with the rare occasions when unethical behavior is detected.

As the Molecular Biosciences develop even faster and as the potential for material rewards increases, competition for priority in publication becomes keener. This can lead to misrepresentation of data, fabrication or falsification of results, lack of consultation with all co-authors, and the omission of reference to related or similar published work by others. It can also lead to release of data and conclusions in the popular media prior to publication in a peer-review journal. Science remains, nevertheless, a collaborative effort, and education must emphasize the interdependence of scientists 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 accept the ethical precepts that have characterized science and give due consideration to the implications of their work on the broader society. Their education should include appropriate discussion of these precepts and develop the ability to work ethically in groups. Candidates should be aware of the ethical implications of their research and of their responsibilities as scientists. Although seminars and courses are frequently seen as a way to achieve awareness of ethical standards, it is the example of role models and especially a candidate's principal supervisor that is most important. Every opportunity should be taken to present and discuss ethical standards during each of the degree programs. (See IUBMB Code of Ethics)

VI. Role of Formal Courses

Especially appropriate in the early part of each of the graduate programs are short courses or workshops in transferable skills (e.g., on scientific writing, presentation of talks, bioethics and professional ethics, time and project management, information storage and retrieval, recording of experimental protocols and results, intellectual property rights, acquisition and management of research grants, laboratory safety, guidelines on human experimentation and handling of animals, library and computer skills and statistics) . These are likely to improve effectiveness and research performance and enhance the likelihood of successful entry into future careers. Such courses or workshops are frequently offered by colleges or boards of graduate studies, and by staff development units, but many large departments with many candidates organize their own. Generic or specialized courses, interdepartmental teaching, and formal student-run seminars are useful in building confidence and promoting a sense of collegiality.

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 education and training is the acquisition of self-direction and familiarity with the pertinent literature, formal courses are useful only if they prepare the candidate for life-long learning or for research activity. They should therefore involve the use of the literature by traditional and electronic means and should emphasize active self-education. Since independent scientists need to keep up with developments in their field, any required specialized courses should be directed toward this future need.

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 (e.g., journal-club activities, reviews of the literature and other literature-based activities, seminars on topics unrelated to the research). Because of these considerations formal courses should be limited in number and in duration.

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. Grades obtained in such courses should not contribute in a major way in the final evaluation of candidates. In countries where academic and scientific resources are limited, inter-institutional cooperation can make up for local deficiencies. We consider realistic and courageous the decision of various departments of Molecular Biosciences not to offer programs for graduate degrees because they lack the proper human, economic, physical, and technical resources.

Specialized courses in the Molecular Biosciences should be designed not just to increase the knowledge base, but also to make candidates more professional in their work and to enable them to become effective communicators. They should be interactive in style so as to develop higher-level intellectual skills rather than the transient accumulation of memory-based information. The assessment procedures should test for these skills rather than for rote learning. Such courses often promote active learning via problem-based learning, process-oriented guided inquiry, and case studies. They should also contribute to the development of a professional attitude and value system.

VII. Responsibility of the Research Supervisor

A research supervisor should have an ongoing research effort and, ideally, should have contributed to the peer-review literature. Through interaction with candidates in planning and programming of the work and in setting and keeping of deadlines, supervisors represent the most important external influence in the learning and development that occurs in students' training. Progress in research depends on the nature, frequency and quality of supervision (particularly through the given critical feedback and monitoring of progression of the work) provided to candidates, especially in the early stages. It also depends on the willingness of the supervisor to accommodate, within reasonable limits, the personal life of a candidate and on the supervisor's acceptance of candidates without pre-conceived notions about their ability to succeed in science. It is good and recommended supervisory practice that short notes be filed for a minimum number of meetings as agreed to by the candidate and the supervisor.

The role of the supervisor in directing student research is one that requires subtle adjustments in personal perspectives and behavior towards the candidate. In general, candidates begin with little relevant knowledge, restricted skills and limited perspective, and usually require a considerable amount of guidance. However, the naive beginner must evolve into a self-reliant and professional investigator during the thesis work. Development of the many personal and professional skills necessary for research, for other future careers, and for self-direction, is acquired only through practice and feedback. The supervisor must decrease detailed direction as the project proceeds and the candidate becomes more self-reliant, and may have to accept, within reasonable limits, a degree of loss in efficiency in the work of the laboratory as part of the cost of professional education. The supervisor and candidate thus gradually become mutually-respecting colleagues participating in a joint research project. The number of candidates that any supervisor can handle should be restricted to within reasonable limits.

Supervisor and candidate participate as partners in a mutual effort but not as equals. In the event of difficulties in the relationship, a clear and explicit route for their resolution should be available. Because the process of education and training contains a major element of apprenticeship, the supervisor is not only a teacher and mentor but also a major determinant of the candidate's relationship with the scientific community and of professional opportunities. Creation of professional networks by a candidate (e.g., through participation in scientific meetings, through the Internet) should be mediated and encouraged by the supervisor. Because this may be the single most important career decision that a candidate for a graduate degree makes, there should be ample time for choice of the thesis topic and supervisor following exposure to several possible supervisors. Attempts by potential mentors to induce candidates to train with them other than by open methods are to be discouraged.

It is the supervisor's responsibility, in discussion with the candidate, to decide when a project is not being productive and to take steps to make it more productive. To avoid wasted time and effort, if at all possible, an unproductive project should be replaced by a new one. At the end of a candidate's program, the supervisor should ensure that all details of experimental procedures and results, any statistical analysis, ideas from discussion with the candidate and conclusions derived, are recorded clearly and assigned for safekeeping.

VIII. Responsibility of Other Academics

Though the graduate education process is based largely on the human and scientific aspects of the supervisor-candidate relationship, complete training of the candidate to meet these standards is very frequently beyond the ability of one person. Other academics with experience in research and supervision and in specialized fields (e.g., statistics, new techniques) have an important role to play and should be members of the candidate’s supervisory committee. This should not be chaired by the supervisor and should meet at least once a year, keep written records (copied to the candidate) on progress and on advice given, and ideally include a member from outside the candidate’s department. This committee makes the supervisor accountable and identifies and deals with any inappropriate conduct. It broadens the scope of the learning environment and also demonstrates the social and interactive nature of scientific research and thinking within the local and the international scientific community. This interaction is increasingly dependent upon networks and a team-based approach.

The committee's functions include: approval of the program of training and of the project; monitoring and periodic assessment of progress; decisions on the candidate's adequacy for continuation in a doctoral program or in transferring from another program; and determination of when enough work has been done to satisfy the requirements. It should give attention to ongoing assessment of the overall quality of the research being conducted and not just the progress being made. Feedback to candidate and principal supervisor should be provided regularly, preferably on at least an annual basis.

It is the responsibility of the department concerned: to define procedures for selection and evaluation of candidates and of requirements (including timing, methods of evaluation and expected standards) for granting the degree; to provide the appropriate physical and intellectual environment in which the skills and competencies outlined in Section IV can be acquired; to ensure appropriate and proper supervision for the candidate; and to enunciate a clear policy on authorship, intellectual property, and procedures for grievance and appeal. The department should also make provision for the development of supervisors, for guidance and tuition of candidates in the English language as may be necessary, and for an environment that promotes the general and professional well-being and development of its candidates.

IX. Responsibility of the Candidate

A graduate degree program must be as concerned with the candidate's intellectual and scientific growth as with the quality and merit of the work for, and reported in, the thesis. For satisfactory and effective achievement of these, candidates must be knowledgeable about and actively involved in the process and mindful of their responsibilities. These include: familiarity with and observance of the appropriate regulations, requirements and guidelines prepared by the department, supervisor and/or other academics involved; familiarity with the handling and care of equipment and materials to be used in the research work; maintenance of professional and ethical relationships at all times with their laboratory coworkers and members of the department; participation in and contribution to the intellectual and scientific community provided by the department; attendance at all assigned courses and other activities; and assurance that all original data on the research work are recorded diligently and assigned for safekeeping in the department for the period designated by the department and/or institution (this is usually no less than five years after completion of the thesis work). A satisfactory relationship between supervisor and candidate is one that is beneficial and supportive and that contributes to the shaping of attitudes, skills and insights of both.

X. Funding of Graduate Research Training

The rapid expansion of scientific training during the past fifty years has been associated with large increases in cost. This cost has often been provided by government funding. Recently, additional support has become available from commercial firms. In some instances, the candidate may be required to meet some of the expense. However, the source of funding should make no difference to the requirements for the award of a graduate degree or to the requirements and standards that are to be met.

Funding by industry has been beneficial for both the universities (e.g., through their being perceived as cooperating with industry) and for graduate candidates concerned (e.g., through stipends that can be more generous than those provided by public funding, and through better prospects for future careers). Industry also benefits through: getting some of its research done on a contractual basis, enhancement of its scientific respectability, perceived generous co-operation with universities, having research data at its disposal soon after they are obtained, and increased publicity.

Frequently, however, industry insists on the signing of confidentiality agreements by the candidate, supervisor and external examiner(s). This usually involves restrictions on the release of data derived from the research, be it in seminars, abstracts, posters, publications, or the thesis. It should be emphasized that award of graduate degrees should not be made on the basis of work whose validity depends upon confidential research. Research projects sponsored by industrial grants or contracts should not impose unreasonable restrictions on dissemination and publication of work done, even when the data may be unfavorable to the sponsor. It is the principal investigator's responsibility to ensure the financial support of candidates for graduate degrees for the duration of the required work. Any conflicts of interest ideally should be resolved amicably and the implications of the research for the broader society should be discussed thoroughly between the candidate and the supervisor.

XI. Duration of Graduate Research Training

Many candidates enter graduate degree programs directly from a Bachelor's degree with little preparedness for the marked differences between undergraduate and graduate research and the day-to-day uncertainty of such work and for the expectations that supervisors may have of them. Transition involves many changes in status, style of work, scope of intellectual problems to be faced, confidence and even self-esteem. Most candidates would benefit from a period of placement in laboratories of different supervisors to permit exploration of a variety of laboratory techniques and research problems, supplemented by short courses or workshops on a variety of transferable skills. Some students will need specific coursework to complement their undergraduate education. At this stage, a candidate's aptitude for research and scholarship at the appropriate level can be assessed.

The transition from student to self-directed scientist does not proceed at the same rate for different individuals. An even greater variable is the time for completion of research projects. It is not reasonable to expect that the requirements for a Doctor degree can be completed within a reasonably short period of time. Where outside forces (usually government ones) apply economic influences to restrict the time for graduate training, members of the profession should resist pressure to award degrees prematurely or to reject students who could become useful professionals given longer periods of training. The award of a graduate 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 candidates are expected to acquire or develop a professional philosophy and professional values in addition to technical knowledge and skills, regardless of success in research, it seems reasonable that training for the Doctor degree should not be less than three years with a maximum of five for full-time candidates.

The progress of every candidate should be monitored and documented by the supervisory committee. Decisions about abandoning unproductive projects should not come suddenly and at a late stage, but should arise from discussions with the candidate while there is still time to complete the degree within the conventional period. Time limits should be flexible and retention of competent candidates within a program simply because they are productive should be discouraged.

XII. Thesis

The graduate thesis or dissertation, presented and defended orally preferably before at least one external expert (who should not be a co-author in any previous work done by the supervisor or other member of the research team) and the supervisory committee, is the ultimate evidence that the candidate has acquired the skills and abilities required for certification as a competent and a self-reliant (Doctor) scientist. It should demonstrate that the candidate has conducted successful and meaningful research by solving an original problem with an increasing degree of independence, has made significant contributions to the work, and understands how the results fit into the scheme of current knowledge. Writing of the thesis should be the candidate's responsibility. However, it must be recognized that such a thesis is likely to be the largest and most demanding single piece of writing that most candidates are ever likely to produce. Thus, a supervisor or other involved academic should not refrain from helping a candidate improve the presentation and style of early drafts of a thesis especially when the candidate's first language is not English. The thesis should preferably be in English, or at least contain an extended summary in that language. Final evaluation of the thesis should be the responsibility of one or more experts invited from outside the department. Institutional structures for review of comments of external examiners on the competence and performance of candidates contribute to ensuring uniformity in the application of standards.

The Doctoral thesis may take different forms. At one extreme, it may be a lengthy document that provides a thorough review of the literature, an explanation of the problem(s) selected, detailed descriptions of the methods, a complete presentation of the experimental results, and an extended discussion of the interpretation and implication of the findings. At the other extreme, one that is not universally accepted, it may consist of one or more published papers with a general introduction and a thorough discussion of the research project. Since it is not possible easily to evaluate the candidate's contribution to any formal publications, especially when there are other authors, and since journals restrict the amount of explanatory and interpretive material, the thesis should include material written by the candidate that supplies information beyond that included in the published papers. It should delineate clearly the candidate's contribution and how the candidate has put the research into scientific perspective. Such material should introduce each publication used as part of the thesis and should discuss the significance of the research and its implications for future investigations or applications.

An acceptable thesis Doctoral degree is one that: is written in a fluent, non-repetitive, direct and clear style; contains a critical review of appropriate previous literature on the topic; contains a clear, detailed and easily-reproducible description of any technique that is used; presents all experimental results including those on the controls that were used and any appropriate statistical analysis, that provide answers to questions that were clearly formulated; contains a balanced and honest discussion of the results including those on controls; presents conclusions that are realistically based on the results; acknowledges all help and assistance that may have been provided to the candidate. If the presentation or the experimental design including controls is considered to be faulty or inadequate, and the defects are unlikely to be corrected within a reasonable period of time, the thesis should be rejected. Any deficiency in the thesis should be made up to the satisfaction of the supervisory committee. The award of the degree should be based solely on the quality of the research and of the thesis.

Much research nowadays is done in large laboratories in which several candidates, technicians, and post-doctoral fellows contribute to a project. Under such circumstances, clear delineation of the contribution made by the candidate is essential in a thesis, and the work done by others should be explicitly defined and acknowledged appropriately. The size or volume of thesis material should not be used as a criterion in its evaluation.

When publications form part of a thesis, the high cost of publication in some prestigious journals should be borne in mind.

Prior publication of material to be included in a thesis for a Doctor degree should be encouraged. The rapid pace of scientific development requires that all meaningful and original research be published as rapidly as possible. This degree should normally only be awarded for a thesis which contains original work which has already been published with the candidate as primary author or which is deemed by the examining body to be suitable for publication in an established, refereed journal in the field. However, it must be recognized that a candidate may sometimes meet all the requirements but not achieve results that are publishable. The award of this degree solely on the presentation of published papers, without any component of formal education and training, is to be discouraged. The award should be based solely on the demonstrated capacity of the candidate to meet these standards.

XIII. Final Words

These Recommendations articulate the process and understanding of many of the problems involved in the education and training of biomolecular scientists as signified by the award of a degree in any of the Molecular Biosciences. Experience in various institutions and countries has shown that successful molecular bioscientists can be produced by diverse routes and systems and meet the Standards described here. It is hoped that the Recommendations and Standards here presented will prove helpful to all involved in the award of these degrees.

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Copies of this booklet can be obtained from the General Secretary (contact information available on the IUBMB homepage), from where the standards can also be downloaded:

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