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Biochemistry/Molecular Biology and Liberal Education

Teagle Group

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**BIOCHEMISTRY/MOLECULAR
BIOLOGY AND LIBERAL
EDUCATION:
A Report to the Teagle
Foundation**



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PREFACE

The disciplinary societies are an often overlooked resource in the improvement of undergraduate education and enhancement of student learning. For this reason, the American Society for Biochemistry and Molecular Biology (ASBMB) was pleased to respond to the Teagle Foundation's call for proposals on "The Disciplines and Undergraduate Liberal Education." The Foundation's grant allowed a Working Group of ASBMB members to assess how the recommended curriculum in biochemistry and molecular biology (BMB) is implemented at a range of institutions, and also provided an opportunity to consider the relationship of a hierarchical, interdisciplinary science major such as BMB to broad educational goals.

After one and a half years of surveys, interviews, and discussions we find reasons for both optimism and concern. The good news is that the skills recommended for BMB majors by the Society resonate with the membership. Department chairs and program directors report that these skills – which include a wide range of intellectual and practical skills, transferable to all areas of study – are integral to their courses and majors. There is great value placed on undergraduate research and integrative thinking, and ASBMB members are at the forefront of creating and assessing effective educational approaches. The bad news is that most students are not given the opportunity for higher level learning since the majority of introductory courses (and even many intermediate and advanced ones) are content driven and do not include elements of active learning. Further, the number of students and the relative weight of research *vs.* teaching in professional advancement discourage faculty at research institutions from examining and modifying their teaching practices.

The recommendations of the Working Group run from the self-evident (more communication between those at research universities and small colleges) to the far-reaching (consider an accreditation system). The main goal of this report is to bring information about current practice, and ideas for assessment and improvement to the membership of ASBMB and those in related fields. Educational and research activities are necessarily linked in our profession. We hope that the report and the response to its findings will give education a more central place in ASBMB's mission.

Adele J. Wolfson, Chair
Teagle Working Group for ASBMB

EXECUTIVE SUMMARY

In November of 2006, the American Society for Biochemistry and Molecular Biology (ASBMB) received a grant from the Teagle Foundation. The Foundation provides leadership for liberal education, supplying resources and opportunities for individuals and institutions to think about and improve undergraduate education. The Foundation's aim for this particular program was to engage disciplinary societies in assessing the relationship of the goals of undergraduate concentration in their disciplines to those of a liberal education. ASBMB was one of only six societies to receive the award, and the only scientific society.

“Liberal education: A philosophy of education that empowers individuals with broad knowledge and transferable skills, and a strong sense of values, ethics, and civic engagement. Characterized by challenging encounters with important issues, and more a way of studying than specific content, liberal education can occur at all types of colleges and universities. “General Education” and an expectation of in-depth study in at least one field normally comprise liberal education.”
-American Association of Colleges and Universities

The Teagle grant provided ASBMB with an opportunity to examine undergraduate programs in biochemistry and molecular biology (BMB) and evaluate the success of their graduates. The Society first published a recommended undergraduate curriculum 16 years ago, and has modified it in recent years to emphasize skills rather than coursework. In spite of publishing these goals, ASBMB had never systematically asked departments how these skills are imparted or what outcomes we would expect if they were put into practice. A Working Group of Society members developed a plan to consider how the skills and competencies of the recommended curriculum are incorporated into programs at a range of institutions, and also the broader question of what BMB contributes to a liberal education. We employed surveys, interviews, and open discussion at our national meeting to address these questions. We hope that this report is

useful not only to the members of ASBMB but also to other professional societies in the US and abroad.

Conclusions

1. About half of the institutions surveyed explicitly follow ASBMB's recommended curriculum. Most departments do include the elements of the recommended curriculum.
2. Professors and scientists in the biomedical industry report that BMB major is strong on intellectual and practical skills, but lacking in skills for personal and social responsibility.
3. Integrative and critical thinking is valued, but appears mainly at the advanced level (use of primary literature, open-ended research projects).

4. Pedagogy, especially at the introductory and intermediate levels, is not reflective of research on student learning. Lecture format is emphasized in at least 80% of classes at all levels.
5. Sustained undergraduate research is valued more highly than other preparation for graduate school and employment. Students gain many of their skills and knowledge from research, but the experience typically begins in the junior year and is limited to a sub-set of undergraduates.
6. The students in BMB courses and programs fall into three categories: (1) those who will continue in BMB professions; (2) those who will go on to other science-related professions, especially medicine; and (3) those who will not make further direct use of their undergraduate BMB degree. Most of the attention of faculty is directed to the first group.
7. Textbooks are seen as references, not drivers of curriculum.
8. There is still a deep divide in the BMB community between those who view themselves primarily as researchers and those who view themselves primarily as teachers.
9. The Society is limited in its ability to drive change in programs and curricula because of the lack of accrediting power.

Recommendations

1. Given the central role of undergraduate research, programs should be designed to ensure a solid foundation of course work that allows students to go on to a meaningful research experience. There should be further discussion of what constitutes a “meaningful” experience, and whether or not it is practical to provide this experience for all majors.
2. We need a better articulation of the difference between the B.A. and B.S. and how well students can be prepared with either degree for different career paths. Institutions that grant only a B.A. should provide advising on what courses, including research, should be included in the program of students intending further study in the field. Graduate faculties and employers should be made aware of the broad education and “cross-training” of a B.A.
3. Provide opportunities for undergraduate and graduate faculty members, undergraduate and medical school faculty members, and also undergraduate faculty and industrial scientists to meet and discuss what each assumes from the other and when specific skills and knowledge are appropriately imparted.
4. Work to publicize broadly those innovative, effective pedagogies that are already in use in the BMB community. In spite of much evidence that the lecture format is the least effective for long-term learning or excitement about the discipline, most courses

are taught in this way. Educational sessions at our annual meeting and publications in *Biochemistry and Molecular Biology Education* have not successfully disseminated better methods. Workshops, which provide active learning for scientist/educators, may be more effective.

5. The officers of ASBMB and the Society's Education and Professional Development committee should consider the benefits and costs of developing an accreditation system.
6. Provide assessment tools for student learning and program evaluation for Society members.
7. Reconsider the recommended curriculum and skills for the BMB major. Some skills have become more important since the publication of the earlier list and might be named specifically (visualization, advanced quantitative skills including modeling, citizenship and engagement with the public).

INTRODUCTION

The defining task for undergraduate departments is the design of a major – the number of courses, course content, and other requirements such as research. Department members must weigh the desire to produce graduates superbly prepared for further study against the charge that the major requires too large a share of an undergraduate’s course options. This dilemma is particularly striking for the sciences at undergraduate institutions, where faculty are committed to the breadth of the liberal arts but also pride themselves on the numbers of students going on to graduate work or employment in scientific fields.

Biochemistry and molecular biology (BMB) are often among the most demanding majors in terms of course requirements. In addition to the linear nature of all science programs, which hinders the flexibility of a major, BMB are interdisciplinary fields that present the further challenge of integrating material from courses in different departments so as to create deeper understanding. There is sometimes tension between contributing departments, and the tendency is to increase the number of required courses rather than to examine content and evaluate learning.

“The department or program is the point at which faculty translate abstract learning goals into practice. Increasingly, an important resource for departmental leaders at the campus level is found through their national disciplinary societies, many of which are actively engaged in identifying, distilling, and promoting best practices in the undergraduate setting.”
- Jeanne Narum, director of Project Kaleidoscope

Since 1992, the American Society for Biochemistry and Molecular Biology (ASBMB) has supported a recommended curriculum for the bachelor’s degree in BMB. This curriculum has been modified in the years since it was developed to emphasize skills rather than coursework. In addition to defining core content in chemistry, biology, and allied fields, the Society has published a list of skills to be achieved (<http://www.asbmb.org/CareersAndEducation.aspx?id=432>).

Although expressed in language specific to the sciences, these skills mirror the learning outcomes from the Association of American Colleges and Universities’ (AAC&U) LEAP initiative (<http://www.aacu.org/leap/vision.cfm>), recommending proficiency in inquiry and critical thinking, written and oral communication, quantitative reasoning, computer literacy, teamwork, ethical reasoning, and integrative learning.

Mapping the two sets of skills on one another provided the Teagle Working Group with an idea of where the ASBMB guidelines are strongest and where they might be supplemented (Table 1).

The Working Group sought to learn how widely the recommended curriculum/skills are understood by departments, at what level skills are introduced, what methods of pedagogy are employed, and how often open-ended research problems are presented to students. These questions were addressed by surveys to department chairs and instructors. Broader ranging questions about the role of BMB in a liberal education were approached through interviews and open sessions at the Society’s national meeting.

Table 1. AAC&U LEAP and ASBMB learning outcomes.

LEAP	ASBMB
Knowledge of Human Cultures and the Physical and Natural World	
<ul style="list-style-type: none"> • Study in the sciences and mathematics, social sciences, humanities, histories, languages, and the arts 	<ul style="list-style-type: none"> • Understanding of the fundamentals of chemistry and biology and the key principles of biochemistry and molecular biology
Intellectual and Practical Skills	
<ul style="list-style-type: none"> • Inquiry and analysis • Critical and creative thinking • Written and oral communication • Quantitative literacy • Information literacy • Teamwork and problem solving 	<ul style="list-style-type: none"> • Ability to assess primary papers critically • Good quantitative skills • Ability to design experiments and understand the limitations of the experimental approach • Ability to interpret experimental data • Ability to design follow-up experiments • Ability to work safely and effectively in a laboratory • Awareness of the available resources and how to use them • Ability to use computers as information and research tools • Ability to collaborate with other researchers • Ability to use oral, written, and visual presentations to present their work to both a science-literate and a science-non-literate audience
Personal and Social Responsibility	
<ul style="list-style-type: none"> • Civic knowledge and engagement-local and global • Intercultural knowledge and competence • Ethical reasoning and action • Foundations and skills for lifelong learning 	<ul style="list-style-type: none"> • Awareness of the major issues at the forefront of the discipline • Awareness of the ethical issues in the molecular life sciences
Integrative Learning	
<ul style="list-style-type: none"> • Synthesis and advanced accomplishment across general and specialized fields 	<ul style="list-style-type: none"> • Ability to dissect a problem into its key features • Ability to think in an integrated manner and look at problems from different perspectives

SURVEY FINDINGS

Explanations of the project and links to on-line surveys were sent to all undergraduate BMB departments in regular contact with ASBMB through the Society's graduation survey. The information was also posted to several on-line fora of science educators. We received approximately 100 responses from department chairs. Instructors at the same number of institutions filled out instructor surveys for 320 courses. Fifty-five institutions completed a later survey on research skills. (Findings of a small survey, directed to scientists in industry, are reported in the next section on interview findings because of the small sample size and the qualitative nature of the responses.)

The chair survey revealed that:

- Fifty-nine percent of schools grant only a B.S. in BMB, 20% only a B.A., and the remaining 21% of institutions grant both degrees. The major goes by many names; the vast majority are within Chemistry (or Chemistry and Biochemistry) or Biology departments.
- Approximately half the schools surveyed take into account ASBMB guidelines when designing their majors. Most of the others are aware of the guidelines but do not use them explicitly. Only 12% were unaware of the guidelines.
- The biggest change that has occurred to the major since 1990 is an increase in the use of technology (41% of respondents). Other notable changes include introduction of more undergraduate research (29%), addition of more specific coursework (25%), and more assessment of student learning (23%). Over one-quarter of respondents reported no change to the structure of their major over this period of time.
- Many of the transferable skills are taught only at the advanced level: oral communication, 74% at the advanced level only; scientific writing, 75%; reading the primary literature, 83%. Statistics is more evenly divided between introductory and advanced courses, but one-quarter of institutions report teaching no statistics in the context of the major.
- Chairs report that the skills listed in ASBMB guidelines are integral to their programs.
- Opinions were divided on integrated courses (as compared to specific disciplinary ones.) Some think that these are a good idea but administratively difficult to offer; others believe that students first need a strong grounding in specific disciplines before moving onto interdisciplinary work.

The instructor survey provided a more detailed view of how skills are introduced and reinforced over the course of student’s program. Figure 1 demonstrates the pattern for skills in advanced level courses. It is clear that basic skills and knowledge are assumed by the time students reach the advanced level, while more sophisticated skills are first introduced at the upper level.

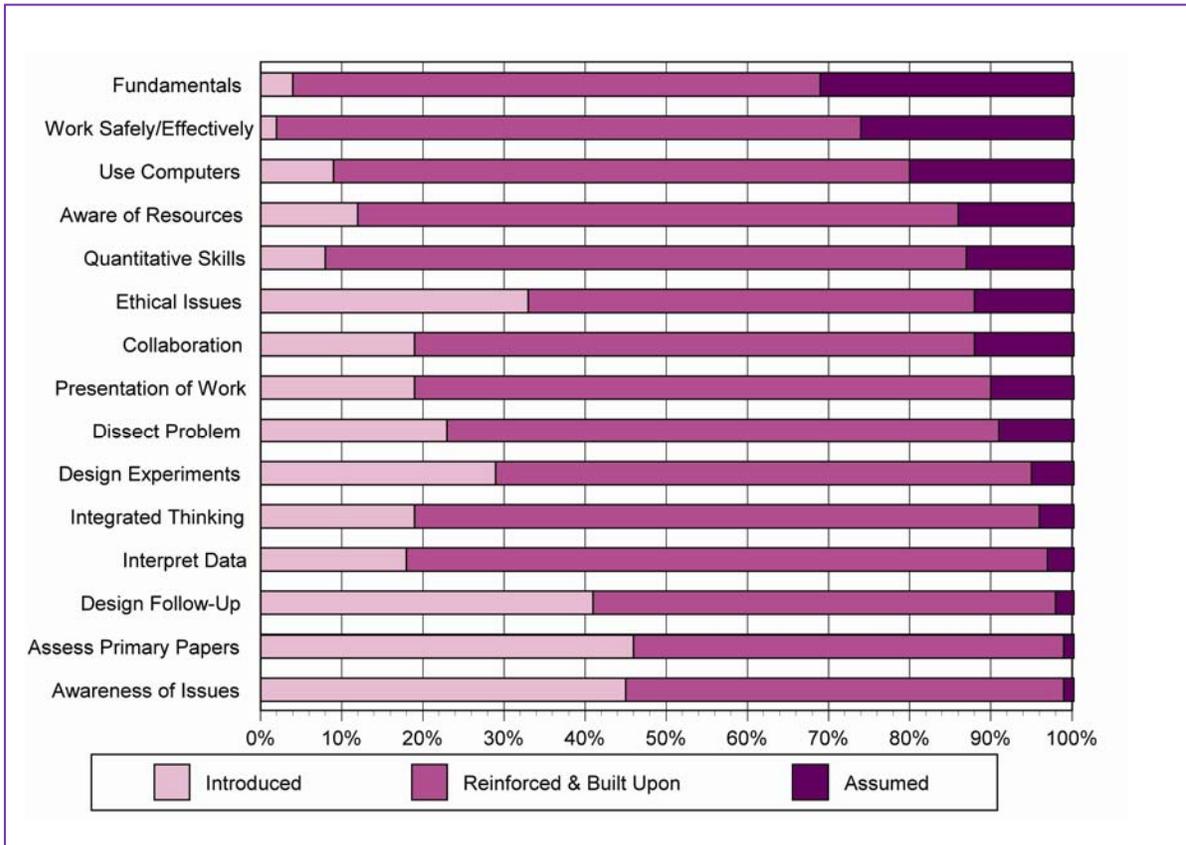


Figure 1. Level of BMB skills taught at the advanced level. The categories listed on the left-hand side of this figure and of Figure 4 are short versions of the skills listed in the table above.

The series of graphs in Figure 2 show the evolution of particular skills from the beginning to the advanced level.



Figure 2. Breakdown of assignments by level. A) Lab exercise that is laid out for students and outcome is known. B) Open-ended problems. C) Read Primary Literature.

Questions about pedagogy revealed that, even at the advanced level, faculty depend on traditional teaching methods (Figure 3).

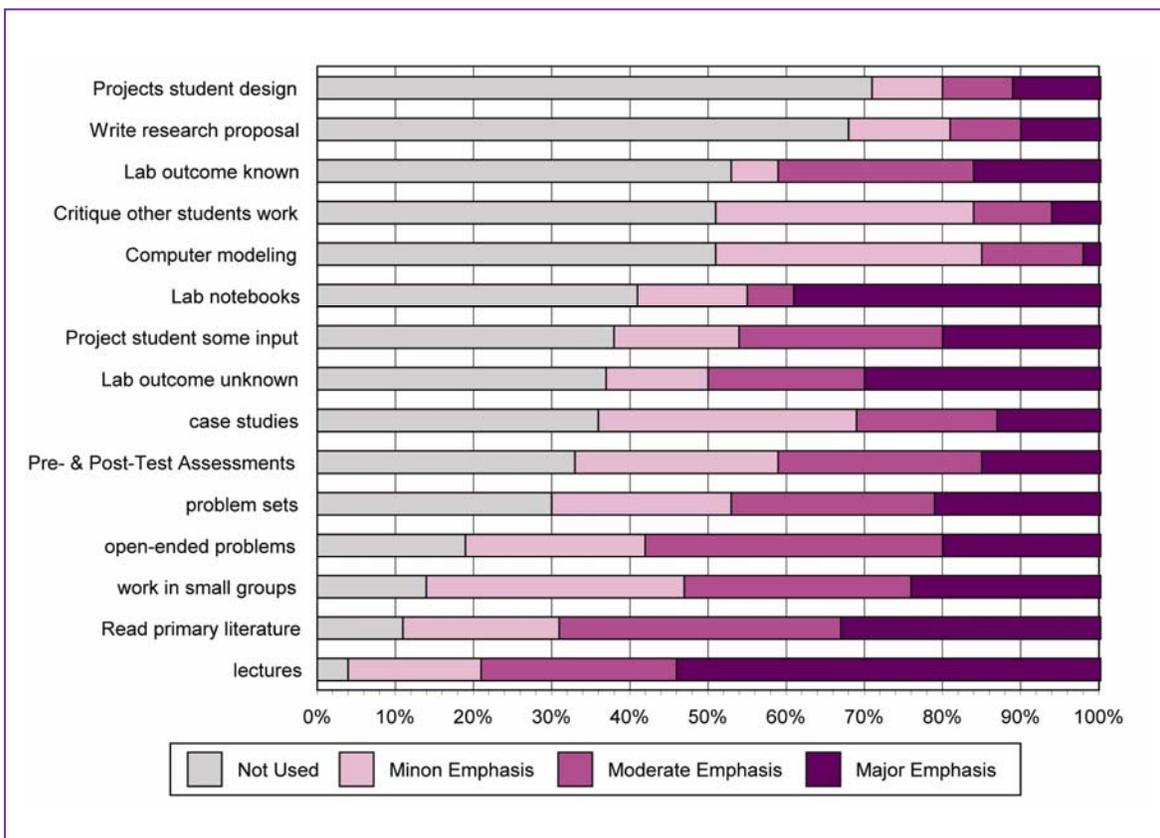


Figure 3. Pedagogical methods used in advanced courses.

The (more limited) research survey revealed that:

- Most undergraduates (61%) begin research in their junior year (6% freshmen, 19% sophomore, 15% senior).
- Seventy-three percent of institutions provide money for supplies for undergraduate research, but only 39% offer teaching credit for supervision of student research.
- About half of programs teach ethics in the context of scientific research.

The pattern of skills taught through undergraduate research is shown in Figure 4. It is notable that many of the skills assumed in research are not taught in the classroom until advanced level courses.

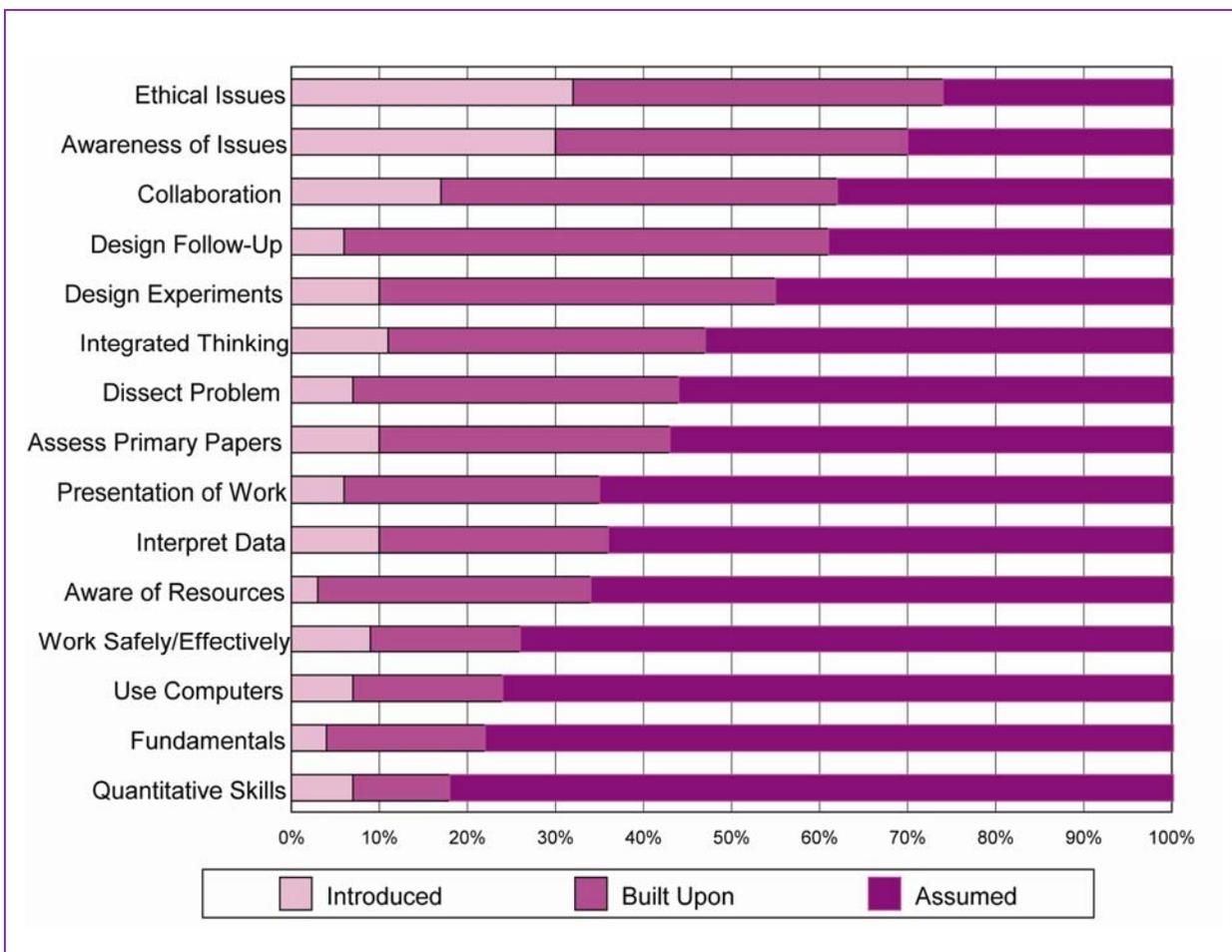


Figure 4. Level of BMB skills taught via a research experience.

Questions Arising From Survey Data

- How do colleges *vs.* universities differ in the pattern of when skills are introduced and employed? Is there a difference by program type (chemistry *vs.* biology *vs.* biochemistry)?
- How are learning gains measured in the different skills areas?
- Are faculty members at different levels aware of what students have learned previously or of how they must be prepared for the next level?
- How do American students compare to those in other countries on measures of content and skill? How do they compare in other areas such as willingness to engage in meaningful give and take with advisors, or independence? How do they compare in success in graduate school?

- What do we mean by a “successful” program or “success” for students? Is it just being able to move on to the next level or is it acquisition of specific skills and competencies?
- What incentives or other strategies can be offered to encourage more effective pedagogies? Can the Society provide more effective guidance, training, and assessment of our own programs?
- We need further information on where our undergraduate majors go after college.

FINDINGS FROM INTERVIEWS AND OPEN DISCUSSIONS

Undergraduate Faculty

There is less difference now than in the past between college and university experiences for undergraduates. The Howard Hughes Medical Institute (HHMI) in particular has brought attention to educational issues, and undergraduate research is now seen as essential. But where we do find differences, it is hard to tell if these are due to curriculum or to smaller class size and more direct interaction with faculty.

Younger faculty in particular felt that liberal arts students develop a skill set that is broader and more flexible than that of students coming from a university. Even when there are wide distribution requirements for students pursuing a B.S, the faculty can signal that they are not to be taken seriously for scientists. The kinds of “soft” skills in working with others, etc, teach students how to draw information from a variety of sources and people and how to gather ideas.

It is hard to assess the effect of undergraduate programs on students’ eventual success because they very often take off time between graduation and graduate programs. The work experience will also influence their success.

Most skills are met through research experiences. One faculty member suggested adding as a skill, “Learn to take responsibility for your own learning.”

Interdisciplinary fields like biochemistry are much more amenable to students from a variety of backgrounds than narrower fields. One of the goals of an interdisciplinary course should be to have the students gain an understanding of its bases in the parent disciplines. We should consider integrated, team-taught, first-year science courses for everyone, not just majors.

Students outside of the sciences just don’t take more science than is required (none if there is no requirement), whereas science majors at liberal arts college take many non-science courses. Science majors are therefore much more broadly educated than their peers. Does this have an effect on their careers?

Students are under a lot of pressure to declare a major from day one. These choices are driven by how well they did in high school courses. If they didn’t do well in high school, they will never take those courses in college. So high school teaching is an important factor, and we have very little control over their choices. Whatever effect we do have has to be right away when they enter college. It is important to dissuade them from the view that science is narrow.

In constructing a liberal arts curriculum, it is difficult to be respectful of all fields while not imposing a false symmetry. Other fields are more accessible than the sciences. It is not clear that the humanities are progressive in the same sense as the sciences (*i.e.*, what was done in teaching English 100 years ago may still be relevant, but this is likely not the

case in Biology). The relationship between history of the discipline and the discipline itself is different for science and other fields.

Graduate School Faculty

A strong research environment for undergraduates is the best preparation for graduate school in the opinion of all surveyed. If the institution doesn't offer such opportunities, it might partner with others that do, or with industrial or government labs. Quality of students makes a big difference. All students can get up to speed eventually, but graduate school advisors want students to hit the ground running. Non-scientists don't see the need for more science for their majors; they see themselves as teaching the same kinds of critical thinking skills within their own disciplines.

It might be desirable to teach history and philosophy of science to science majors (also as a way to teach scientists and non-scientists the way that scientific knowledge is constructed). Lack of time is an issue, but it was deemed to be an excellent way to get to some of the skills we desire, including ethics. Many of the skills are taught as part of a mentored research experience.

Industry

There is consensus in the need for a meaningful research experience, not a "research-like" course. A significant majority of responders deemed a practical, independent research experience as the most important aspect of training for employment in the industrial sector.

Equally valued were strong communication skills, written and oral. Several respondents mentioned the ability to present a well-developed seminar and interviewing skills. Among the other important skills noted were quantitative science skills and exposure to matrix organizations, sometimes built up through teamwork and leadership in other contexts.

Respondents saw no meaningful difference between B.A. and B.S. graduates, although there was a slight preference for B.S. since these students have usually taken more science courses. In either case, electives should complement the major. All saw value in a broad, liberal education. Such an education teaches tolerance, acceptance, and challenge – all important characteristics needed to succeed in an industrial R&D environment. A liberal arts education also hones writing, general communication, and creative thinking skills. Further, a liberal arts education avoids the dangers of overspecialization.

Textbooks

Writers and editors agree that texts are for fundamental knowledge, not skill. Curricular change should come from instructors. But many biochemists believe that textbooks can drive change, with examples from early editions of Lehninger and Stryer. The Wood *et al* problem-based text was also very influential, and there was regret that it had never been updated. Progressive disclosure and problem-based learning can't be done in a textbook, so the burden falls to the instructor.

End-of-chapter questions can be designed to test cognitive skills without too much change to the rest of the text. Upper level books often have less interesting and challenging questions and problem sets than introductory texts, which take advantage of a wide range of real world examples. It can be easier to teach to non-majors because there is no need to worry about “coverage” and building a base for subsequent courses.

Instructors (and students) are overwhelmed by curriculum content goals. Is it possible to coordinate with other disciplines to avoid duplication? The National Science Foundation (NSF) is interested in creating texts that are shorter, contain core concepts only, and allow students to get more specific information from other sources. A related project is the development of a concept inventory (*e.g.*, http://www.altc.edu.au/carrick/webdav/site/carricksite/users/siteadmin/public/carrick_report_science_dec07.pdf).

Most scientists would say that content is not as important as process, but students need terminology and fundamentals as a base and a “hook.” Different scientists disagree on the amount and balance of content and concept. Meaningful assessment is difficult, and most instructors don’t know how to assess beyond content.

Preparation for Careers Other than Research

BMB is good preparation for other careers, but advising is often absent. Pre-college teaching is an especially important career path, not made easy by state and institutional rules. For example, in many states a BMB major would not be eligible to teach chemistry, so there is a disincentive to major in BMB. There are alternative certification programs, including a post-baccalaureate year or summer workshops. As for all teaching programs, there is a high burn-out rate.

We know that many BMB majors or those in BMB courses are planning a career in medicine. How do their needs differ from those going to graduate school or industry? Since so many medical schools now require applicants to take a biochemistry course, the BMB community has the opportunity to define the content and structure of a one-semester course. On the other hand, there is a move to limit the content of pre-medical courses to those deemed most relevant to human biology. This might have the effect of closing off particular areas of research or career paths.

Assessment

We have not agreed on the standards for outcomes assessment and how to determine the benefits for undergraduates of a BMB degree. The difference between a B.S. and B.A. complicates the analysis, also the fact that many students take time off between college and graduate school, so that it is difficult to attribute success or lack of success to undergraduate preparation. We need to find ways to assess skills, as opposed to content, or we can’t know if students are acquiring them. Accreditation is a heavy-handed tool to drive assessment; tools internal to the scientific community would be better suited to our goals.

Questions Arising from Interviews and Discussions

- What do graduate schools really look for in a graduate student? What does industry really look for in a new employee? If they want students/employees who have done research, can that substitute for specific courses or do students need both? How do we reconcile the stated values of employers for broadly educated employees with their preference for those with greater depth in the field?
- What is the relationship of this study to medical school requirements? How does it relate to success in medical school?
- What impact, if any, would ASBMB accreditation have on hiring in the biopharmaceutical or related industries?
- What is the goal of a science requirement for non-scientists? Is it to give students a sense of how scientists work in the lab? Or to be able to read a popular article knowledgeably? Should there be separate courses for non-majors or should we have them take the same courses as those who will continue in the field?
- If we acknowledge that science majors at liberal arts institutions (or universities with broad distribution requirements) are in fact the most liberally educated graduates, what is the result? Are they actually better scientists?
- How do we impart the sense of how knowledge is created in science, to majors and non-majors? Can it only happen in a lab setting or is a history of science course the best way?

RECOMMENDATIONS

Undergraduate Research

The one clear finding of this study was the central importance of undergraduate research in preparing scientists. Our recommendation that programs should be designed to ensure a solid foundation of course work that allows students to go on to a meaningful research experience seems straightforward, but there is much uncertainty and even disagreement underlying that recommendation. What is a “meaningful” experience? A summer? One year? Two years? Must the project have outside funding and/or result in peer-reviewed publication? If we define the experience as an extended period of a year or more and we expect publication-quality research, there will be a shortage of space in faculty members’ labs to accommodate all BMB majors.

The reported learning gains from a research experience have been documented by Elaine Seymour and David Lopatto and their colleagues. Some of the gains are closely connected to specific scientific skills and knowledge: learning lab techniques, understanding the primary literature, skill in interpretation of results. Others are more generalizable and fit well with the LEAP categories: understanding how knowledge is constructed, oral and written presentation skills, learning ethical conduct. Still others relate to students’ self-development: tolerance for obstacles, learning to work independently, self-confidence, clarification of a career path.

Are there other ways for students to gain these skills when a full research experience is not possible? Our Working Group thought not, but an additional study from the Lopatto group suggests that at least some of these are acquired during “research-like” courses. These are courses that include some or all of the following elements:

- a lab or project where no one knows the outcome
- a project in which students have some input into the research process
- a project entirely of student design
- students become responsible for a part of the project
- students critique the work of other students

For courses that scored high in these activities, students reported gaining at least as much and occasionally more than they reported for a research experience in skill in interpretation of results, analyzing data, reading the primary literature, and oral communication. On the other hand, students with a summer or more of research experience reported more gains than those in research-like courses in readiness for more advanced research, understanding how to approach real problems, lab techniques, and independence (www.grinnell.edu/academic/psychology/faculty/dl/sure&cure/). It appears that research-like courses may be good preparation for a “real” research experience but cannot serve as a substitute.

Other models have been proposed to provide a research experience for large numbers of students. At Drake University, LaRhee Henderson and Charlise Buising have pioneered a “one-room schoolhouse” approach that brings students into an ongoing research project starting at a novice level and allowing them to continue to the stage of being co-authors

on papers and presentations. Sarah Elgin at Washington University (MO) has created a research-based course that gives juniors and seniors undergraduates the opportunity to work as a research team through a large-scale sequencing project (www.nslc.wustl.edu/elgin/genomics/bio4342.html). At universities outside the US, the fourth-year post-baccalaureate “honors” level is often utilized to teach research skills and may obtain publishable results.

The BMB community needs to determine if a research experience is a necessary component of every BMB major’s education. If so, more models such as those mentioned above will have to be devised, or formal arrangements for students to work in industry or government labs should be facilitated. Faculty at research universities may be able to provide space in their research labs for larger number of undergraduates than at present, but these students typically work with post-docs or graduate students rather than directly with a faculty mentor. Those faculty at undergraduate institutions with active, funded research programs are generally at capacity with research students, while those with heavy teaching loads have little time or money to take on additional research students.

The B.A./B.S. Question

Liberal arts colleges produce a disproportionate number of Ph.D.s in the sciences (www.nsf.gov/statistics/infbrief/nsf08311/). Those of us at such colleges began this study by assuming that the broad skills gained with a B.A. would be highly valued by graduate schools and employers. Some of us were surprised and somewhat dismayed to hear that depth in the discipline is valued over breadth.

Many scientists (and other academics) believe that “liberal education” is synonymous with “liberal arts education” and do not see the relevance to their institutions and disciplines. As the American Association of Colleges and University’s definition of liberal education (www.aacu.org/leap/What_is_Liberal_Education.cfm) makes clear, a liberal education can occur at all types of colleges and universities. We need to articulate the elements of a liberal education that are essential for scientists operating in society, and then see how this fits into the B.A. vs. B.S. divide. Students can be prepared with either degree for different career paths but need strong advising. Institutions that grant only a B.A. should make clear to students what courses, including research, they will need if they intend further study in the field. Graduate faculties and employers should be made aware of the broad education -- what Tom Cech has referred to as “cross-training” - - of liberal arts graduates. Studies of alumni/ae from liberal arts colleges show that any short-term deficit they have in preparation for graduate school is quickly overcome, and their strong communication and critical thinking skills give them a long-term advantage.

More Communication

The above questions about research preparedness and breadth vs. depth show the need for communication between undergraduate faculty and graduate/professional faculty and employers. The Society should provide opportunities for these conversations to take place, and students at all levels should be invited. Concrete discussions and sharing of syllabi and expectations about what is taught and how it is taught would allow transitions to be handled more appropriately and perhaps lead to greater mutual respect.

Pedagogy

We need to publicize broadly those innovative, effective pedagogies that are already in use in the BMB community. The physics and chemistry education communities have led the way in documenting how active learning techniques improve understanding and performance. There is an extensive literature on the scholarship of teaching and learning in those fields, with respected graduate programs. Biology and its sub-disciplines have lagged behind the physical sciences, perhaps because it is more difficult to articulate core concepts. However, several NSF-funded programs support biology education reform. The American Society for Microbiology manages a research ‘residency,’ for which ASBMB members are eligible, to develop an understanding of evidence-based research in biology education and to help educators develop assessment tools for student learning (www.biologyscholars.org).

"We now have good data showing that traditional approaches to teaching science are not successful for a large proportion of our students, and we have a few research-based approaches that achieve much better learning,"

- Carl Wieman, Nobel laureate in Physics

There are already many examples of effective approaches to teaching of biochemistry that employ more active learning than the usual lecture or problem-solving session. These include problem-based learning (PBL), process-oriented guided inquiry learning (POGIL), peer-led team learning (PTL), Just-in-Time Teaching, and the case-study approach. All of these are based on research about how students learn, and can be adapted for a variety of settings. One method that is particularly well suited to large lecture classes is the use of “clickers.” In spite of much evidence that the traditional lecture format is the least effective for long-term learning or excitement about the discipline, our survey data show that

most courses are still taught in this way. So far, educational sessions at the Society’s annual meeting and publication in *Biochemistry and Molecular Biology Education* have not reached the majority of programs and instructors.

It is important that participants in educational sessions get exposed to practical ideas for teaching, student learning, and curriculum design, and that the ideas actually end up getting successfully implemented. Presenters should have knowledge of both science and educational methods and theory. Even when convinced of the need for new teaching methods, scientists still need assistance in how to implement changes in their own courses. One of the best ways to do this is for the session to include workshops rather than talks, in which colleagues participate actively in applying the educational ideas to an aspect of their own teaching, assessment or curriculum materials. The workshop should end with a short-term evaluation and include longer-term follow-up. Such workshops would not increase the size of the audience for educational sessions but would improve their effectiveness, which might in turn grow the audience. Assessment is another tool for promoting the development of better pedagogy and teaching scholarship. Once instructors create or adopt tests of student learning they begin to question how best to support students and help them develop cognitive skills.

The issue of effective pedagogy is related to the problem alluded to in several places in this report: the separation between ASBMB members whose main focus is research and

those whose main focus is education. The separation roughly corresponds to the divide between research universities and small colleges, although there are certainly many faculty at research universities deeply involved in teaching and many at small colleges who are equally engaged in teaching and research. The lack of attention to pedagogy is certainly not unique to BMB. If we want to broaden the discussion about BMB education, we must consider the reward system in academia, and we must make it easier for faculty to learn about and incorporate new pedagogical methods. Project Kaleidoscope (www.pkal.org) is an invaluable resource for small colleges, and might be made more available to interested faculty who teach undergraduates at all types of institutions.

"These pedagogies [of engagement] work for all disciplines, serve all institutional types, strengthen the learning of all students, and reflect societal and disciplinary goals for undergraduate learning,"
- Jeanne Narum

We cannot underestimate the barriers to changing the culture in ways that promote effective teaching. But the skills-based curriculum recommended by ASBMB is a first step. Assessment of student gains in these skills would move the conversation further. Once faculty members see the gap between desired skills and attained skills they may be motivated to modify their teaching methods. The Society can help by making teaching and assessment resources available to members.

In addition to effective teaching of majors' courses, the Teagle Working Group sought information on non-majors' courses with BMB content. There are certainly one-semester biochemistry courses intended for pre-med or other science students; these are subject to many of the same pressures of content vs. skills and lecture vs. active-learning pressures discussed above. However, there are very few courses for non-scientists, probably because biochemistry and molecular biology build on introductory science courses and would require multiple prerequisites. There are a few examples of first-year seminars created around a particular faculty member's interests, and also integrated introductory science courses that begin with large interdisciplinary problems before drilling down to basic principles (see, for instance, Rob Bellin's course on the biological chemistry of health and disease (www.holycross.edu/departments/biology/rbellin) and Henry Jakubowski's course on (bio)chemistry and society (<http://employees.csbsju.edu/hjakubowski/classes/Chem%20and%20Society/ChemDisM.M.htm>)). We encourage the BMB community to share examples of such courses and evaluate their effect on both student learning and recruitment into the major.

Accreditation

Professional societies that accredit degrees or programs have control over curriculum in ways that cannot be accomplished by mere "recommendation." Many ASBMB members are familiar with the accrediting power of the American Chemical Society; some chafe at the regulations while others welcome the support. ABET (the Accreditation Board for Engineering and Technology) has been able to reform the profession by including changing reaccreditation standards and holding institutions accountable to those Standards (www.abet.org/Linked%20Documents-UPDATE/White%20Papers/Engineering%20Change.pdf).

Recognizing the important role that accreditation can play, the Society is currently discussing the implementation of a potential ASBMB Accreditation program. Whenever issues of curriculum are raised, faculty at small colleges and two year colleges note how useful it would be to them to have the accrediting power of the Society to use as a tool with their administrations in order to keep offering certain courses or convince skeptics of the need for a research program. The education and professional development (EPD) committee is working to determine what elements of an accrediting system would benefit the community of molecular life science educators at all levels and how this might be accomplished.

Assessment

Quite apart from the recent emphasis on assessment on the part of granting agencies and accrediting bodies, it is obvious that cycles of innovation-assessment-evaluation-redesign are as much a part of education as they are of scientific research. The challenge has been to find assessment tools that provide real information about student learning and are accepted by the BMB community.

AAC&U emphasizes that good assessment involves multiple measures over time. Assignments and exams already built into courses can provide one of those measures as long as they are carefully designed and are not just used to produce a student grade. Several publications from AAC&U outline the types of assessment that have been done on individual campuses to address student gains in each of the skills categories discussed earlier in this report. These are further broken down into the level of knowledge and how best to assess at various points in a student's career. We also recommend that instructors and programs use Wick and Phillips's "liberal education scorecard" to determine how elements of liberal education are balanced within their courses and majors.

Individual instructors have created assessment tools appropriate to their teaching techniques. Some of these can be found in this report's bibliography. The PBL web site (www.udel.edu/chem/white/teaching/BiochEd/articles.html) has many additional links. Trevor Anderson's series "Bridging the Gap" in *Biochemistry and Molecular Biology Education* contains both theoretical and practical references on assessment. The ASBMB EPD committee would do a service to the community by maintaining a web site of proven assessment techniques. External reviewers might also review the programs.

Changes to the Recommended Curriculum

The skills that are included in ASBMB's recommended curriculum are indeed the ones considered essential by the membership. As the Teagle Working Group examined the relationship between these skills and those from AAC&U, some gaps became apparent, particularly those in the category of Personal and Social Responsibility. There is no explicit reference to the ways that scientists are engaged with the larger community. Some of our respondents have also suggested addition of "independent thinking" (in addition to teamwork). Besides these general skills, some skills specific to BMB have become more important since the publication of the earlier list. These include visual literacy and advanced quantitative skills including modeling. The EPD should periodically reassess the content and skills recommended for BMB programs.

ACTIONS AND TIME TABLE

Fall 2008

- Publish and disseminate this White Paper to ASBMB membership.
- Share White Paper with other Federation of American Societies for Experimental Biology (FASEB) societies.

Winter 2008/09

- Meet with incoming ASBMB officers and EPD committee members to present findings and recommendations.
- Determine best time for a satellite or stand-alone workshop on Biochemistry and Liberal Education.

April 2009

- If possible, hold a session on this White Paper at the ASBMB Annual meeting.
- Recruit a group of faculty to develop the workshop.
- Attend Annual meeting receptions for young scientists and postdoctoral fellows/graduate students to bring educational issues to their attention.

Summer 2009

- Invite chairs of undergraduate and graduate programs and presidents/chairs of education committees from other FASEB societies to attend the Workshop on Biochemistry and Liberal Education.
- Develop strategies for dissemination of pedagogical ideas to biochemists so that education sessions at the national meetings better achieve their goals.

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APPENDIX A: WORKING GROUP MEMBERS

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Hector Martinez, Director of Information Technology
Steve Miller, Director of Finance

Consultant

Lawrence Baldwin

APPENDIX B: SURVEYS

ASBMB: Department Chair Survey

Demographics

1. Name
2. Institution
3. Department
4. Name of Biochemistry/Molecular Biology Major (If different than Department name)
5. Email Address
6. Degree(s) Granted
BA BS BA&BS
7. List of course meeting major requirements

ASBMB: Department Chair Survey

Survey Questions

1. Does your department/program take the ASBMB guidelines for majors into account in planning curriculum or majors?

Yes, we are aware of the guidelines and try to follow them

No, we are not aware of the guidelines but they do not influence our choices

No, we were unaware of the guidelines

2. How have your major requirements changed since the first ASBMB guidelines were published (1990)? Select all that apply.

No change

We have added more specific coursework.

We have added more skill-based requirements

We require/recommend more undergraduate research.

Our methods of pedagogy have moved away from lecture.

We do more assessment of student learning.

We have decreased the number of courses required Use of technology has increased.

Not relevant – our major was created since the new guidelines (2003)

3. Do you explicitly teach the following skills in courses required for the major?

	No	Yes, in intro courses	Yes, in advanced courses
Reading primary literature			
Scientific writing			
Statistics			
Oral communication			

4. Do you incorporate discussion of ethical issues into courses meeting requirements for the major?

No

Yes, in one course

Yes, in several courses

5. Are students expected to carry out a lab project in which they have input into the experimental design for any courses meeting requirements for the major?

No

Yes, in introductory as well as advanced courses

Yes, only in advanced courses

6. We would appreciate comments you might wish to add on any of the points listed below, or expanded responses to the survey questions. Please use the space given or send comments to awolfson@wellesley.edu.

- Skills might be divided into three groups: those core for a science major; general academic skills such as written and oral communication, computer literacy, teamwork, and integrative learning; and broad skills such as such as citizenship, appreciation of diversity, and ethical reasoning. If you include any of these beyond the core scientific skills within your biochemistry major, do you your students and faculty view them as integral to the major or as optional, unimportant “add-ons”?
- What evidence will be taken as sufficient by the biochemistry/molecular biology community that new teaching methods and a broader curriculum produce graduates at least as good as those trained in traditional ways?
- Can a student majoring in a different field gain skills in inquiry and critical thinking through taking a biochemistry/molecular biology course?
- Is an integrated approach (a single course covering several sciences) a better one than separate introductory courses?

7. Would you be interested in follow-up discussions about these issues?

Yes
No

8. Do you teach a course or courses that are required for the Biochemistry/Molecular Biology major?

Yes
No

Biochemistry/Molecular Biology Program Skills Inventory

1. **Institution**
2. **Course**
3. **Instructor**
4. Below is a list of skills identified by ASBMB as necessary for students completing a major in biochemistry/molecular biology. The Society is interested in knowing where in the curriculum these skills are taught. Please check the appropriate box for each skill for your course. (If you teach more than one course that is required for the major, please fill out a separate form for each.)

Thank you! If you have comments, please add them in the space below the grid.

	Skill is introduced	Skill is reinforced and built upon	Skill is assumed	N/A
Understanding of the fundamentals of chemistry and biology and the key principles of biochemistry and molecular biology				
Awareness of the major issues at the forefront of the discipline				
Ability to assess primary papers critically				
Good quantitative skills such as the ability to accurately and reproducibly prepare reagents for experiments				
Ability to dissect a problem into its key features				
Ability to design experiments and understand what the experimental approach can and cannot tell you				

	Skill is introduced	Skill is reinforced and built upon	Skill is assumed	N/A
Ability to interpret experimental data and identify consistent and inconsistent components				
Ability to design follow-up experiments				
Ability to work safely and effectively in a laboratory				
Awareness of the available resources and how to use them				
Ability to use computers as information and research tools				
Ability to collaborate with other researchers				
Ability to use oral, written, and visual presentations to present their work to both a science-literate and a science-non-literate audience				
Ability to think in an integrated manner and look at problems from different perspectives				
Awareness of the ethical issues in the molecular life sciences				

5. Comments

Biochemistry/Molecular Biology Course Elements Inventory

1. Course

2. Instructor

3. Below is a list of elements or methods of pedagogy that might be included in your class. Please check the appropriate box for each element for your course. (If you teach more than one course that is satisfied requirements for the biochemistry/molecular biology major, please fill out a separate form for each.)

	Not Used	Minor emphasis	Moderate emphasis	Major emphasis
Lectures				
Work in small groups				
Case studies				
Open-ended problems				
Problem sets				
Lab exercise that is laid out for students and outcome known				
Lab project with unknown outcome				
Project in which students have some input as to research design				
Project entirely of students' design				
Read primary literature				
Write research proposal				
Students critique work of other students				
Students maintain lab notebook				
Computer modeling				
Pre- and post-test or other assessment				

4. Comments

ASBMB Education Survey

Please fill out this survey and return your answers to awolfson@wellesley.edu or mail them to:

Adele Wolfson
 Wellesley College
 Office of the Dean of the College
 106 Central Street
 Wellesley MA 02481

The survey can also be filled out online at _____ (INSERT WEBSITE)

1. Is your institution a University or College?
2. Is the degree granted by your program BA, BS or BA&BS?
3. For each of the following skills indicate whether students are taught it in the context of their research experience in your department/program.

		skill not taught	skill introduced	skill reinforced and built upon	skill is assumed
a	Understanding of the fundamentals of chemistry and biology and the key principles of biochemistry and molecular biology				
b	Awareness of the major issues at the forefront of the discipline.				
c	Ability to assess primary papers critically.				
d	Good "quantitative" skills such as the ability to accurately and reproducibly prepare reagents for experiments.				
e	Ability to dissect a problem into its key features.				
f	Ability to design experiments and understand the limitations of the experimental approach.				
g	Ability to interpret experimental data and identify consistent and inconsistent components.				
h	Ability to design follow-up experiments.				
i	Ability to work safely and effectively in a laboratory.				
j	Awareness of the available resources and how to use them.				
k	Ability to use computers as information and research tools.				
l	Ability to collaborate with other researchers				

(Question 3 continued)

		skill not taught	skill introduced	skill reinforced and built upon	skill is assumed
m	Ability to use oral, written and visual presentations to present their work to both a science literate and a science non-literate audience.				
n	Ability to think in an integrated manner and look at problems from different perspectives.				
o	Awareness of the ethical issues in the molecular life sciences.				

4. Does your department/program teach ethics in the context of scientific research?

No Yes

5. At what year/level do your molecular biology/biochemistry undergraduate students typically do scientific research?

first year sophomore year junior year senior year

6. Does your institution supply money for undergraduate research?

No Yes

7. Does your institution offer teaching credit for supervision of undergraduate research?

No Yes

8. Does your institution offer a general education course in biochemistry/molecular biology that you consider to be an excellent model?

No Yes

If so, please send syllabus to (INSERT EMAIL ADDRESS)

9. How does your institution define the success of your programs and graduates? (Please briefly describe).

10. If you would like to be involved in further discussion and implementation of any new recommendations?

No Yes

Please indicate your email address below.