FEATURED TOPIC

THE AMERICAN SOCIETY FOR BIOCHEMISTRY AND MOLECULAR BIOLOGY

The Biochemistry and Molecular Biology Major and Liberal Education

The one clear finding of this study is that undergraduate research is regarded as centrally important to the preparation of scientists

THE DEFINING TASK for undergraduate departments is the design of a major, including the number and content of courses as well as other requirements. 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 number of students going on to graduate school 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 integrate material from courses in different departments. Tension between contributing departments often leads to an increase in the number of required courses.

Since 1992, the American Society for Biochemistry and Molecular Biology (ASBMB) has supported a recommended curriculum for the bachelor's degree in BMB. In the years since it was developed, this curriculum has been modified 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. Although expressed in language specific to the sciences, these skills mirror the learning outcomes recommended by the Association of American Colleges and Universities (AAC&U) in its 2007 report, *College Learning for the New Global Century* (see p. 32). Mapping the two sets


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Figure 1

AAC&U	ASBMB
Knowledge of Human Cultures and the Physical and Natural World	
• Study in the sciences and mathematics, social sciences, humanities, histories, languages, and the arts	• Understanding of the fundamentals of chemistry and biology and the key principles of biochemistry and molecular biology
Intellectual and Practical Skills	
• Inquiry and analysis • Critical and creative thinking • Written and oral communication • Quantitative literacy • Information literacy • Teamwork and problem solving	• 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	
• Civic knowledge and engagement (local and global) • Intercultural knowledge and competence • Ethical reasoning and action • Foundations and skills for lifelong learning	• Awareness of the major issues at the forefront of the discipline • Awareness of the ethical issues in the molecular life sciences
Integrative Learning	
• Synthesis and advanced accomplishment across general and specialized fields	• Ability to dissect a problem into its key features • Ability to think in an integrated manner and look at problems from different perspectives

of skills onto one another indicates where the ASBMB guidelines are strongest and where they might be supplemented (see fig. 1).

Through a survey of department chairs and instructors, we sought to learn how widely the ASBMB-recommended curriculum and skills are understood by departments, at what levels the skills are introduced, what methods of pedagogy are employed, and how often open-ended research problems are presented to students. Broader-ranging questions about the role of BMB in liberal education were explored through interviews and open sessions at the 2007 ASBMB national meeting.

Survey findings

The survey revealed that 59 percent of schools grant only the Bachelor of Science (BS) degree in BMB, 20 percent grant only the Bachelor of Arts (BA) degree in BMB, and the remaining 21 percent grant both types of degree. The major goes by many names, but the vast majority are housed within chemistry (or chemistry and biochemistry) or biology departments.

Approximately half the schools surveyed take account of ASBMB guidelines in designing their majors, and most of the others are aware of the guidelines but do not use them explicitly. Only 12 percent were unaware of the guidelines.

The biggest change that has occurred to the major since 1990 is an increase in the use of technology. Other notable changes include the introduction of more undergraduate research, more specific coursework, and more assessment of student learning. More than one-quarter of respondents reported no change to the structure of the major over this period of time.

Department chairs reported that the skills listed in the ASBMB guidelines are integral to their programs. However, many of the transferable skills—oral communication, scientific writing, reading primary literature—are taught only at the advanced level. Statistics instruction is more evenly divided between introductory and advanced courses, but at one-quarter of institutions statistics is not taught within the context of the major at all. The instructor survey provided a more detailed view of how skills are introduced and reinforced over the course of a student's program. 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.

Opinion of integrated courses is divided. Some think these are a good idea but administratively difficult to offer; others believe that students first need a strong grounding in specific disciplines before moving on to interdisciplinary work.

Broader findings

Undergraduate faculty. There are fewer differences now than in the past between college and university experiences for undergraduates, and undergraduate research is now seen as essential to both. But where we do find differences, it is hard to tell whether they are due to curricula or to smaller class sizes and more direct interaction with faculty. Younger faculty, in particular, felt that students at liberal arts colleges develop a skill set that is broader and more flexible than that developed by university students. Even when there are wide distribution requirements for students pursuing the BS degree, the faculty can signal that they are not taken seriously by scientists. It is difficult to assess the effect of undergraduate programs on students' eventual success; graduates often take time off before entering graduate programs, and the work experience also has some influence.

Interdisciplinary fields like biochemistry are much more amenable than narrower fields to students from a variety of backgrounds. One of the goals of an interdisciplinary course should be for students to gain an understanding of its bases in the parent disciplines. Integrated, team-taught, first-year science courses should be offered to all students, not just majors. Whereas science majors at liberal arts colleges take many nonscience courses, nonscience majors take no more science than is required—and none at all where there is no requirement. Science majors are, therefore, much more broadly educated. Students are under considerable pressure to declare a major quickly, and the choice is driven largely by how well they performed in high school courses. Students who did not do well in high school courses in particular subjects are unlikely to take courses in those subjects while in college.

In constructing a liberal arts curriculum, it is difficult to be respectful of all fields without 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; that is, what was done in teaching English one hundred years ago may still be relevant, but this is likely not the case in biology. The relationship between the history of the discipline and the discipline itself is different for the sciences.

Graduate faculty. In the opinion of all those surveyed, a strong undergraduate research program is the best preparation for graduate school. If an institution does not offer research opportunities to undergraduates, it might partner with others that do, or with industrial or government labs. The quality of students makes a big difference. All students can get up to speed eventually, but graduate school advisers want students to hit the ground running. Nonscientists do not believe their majors need more science, largely because they see themselves as teaching the same kinds of critical thinking skills within their own disciplines.

A course on the history and philosophy of science could teach both scientists and nonscientists how scientific knowledge is constructed. Such a course was also deemed by

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respondents to be an excellent way to develop some of the desired skills—including ethics—that are currently taught as part of a mentored research experience.

Industry. There is consensus on the need for a meaningful research experience, as opposed to a "research-like" course. A significant majority of respondents deemed practical, independent research experience to be the most important aspect of training for employment in the industrial sector. Equally valued are strong written and oral communication skills. Several respondents also mentioned interviewing skills and the ability to present a well-developed seminar as well as quantitative science skills and exposure to matrix organizations.

Respondents saw no meaningful difference between BA and BS graduates, although there was a slight preference for the latter 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 that teaches tolerance, acceptance, and challenge; these are important characteristics needed for success in an industrial research and development environment. A liberal education also hones writing, general communication, and creative thinking skills. Further, it avoids the dangers of overspecialization.

Textbooks. Textbooks are designed to present fundamental knowledge, rather than to develop skills. The impetus for curricular change should come from instructors, but many biochemists believe that textbooks *can* drive change. Progressive disclosure and problem-based learning cannot 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 less 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 nonmajors because there is no need to worry about "coverage" or building a base for subsequent courses.

Instructors (and students) are overwhelmed by curricular content goals, and it may be possible to coordinate with other disciplines to avoid duplication. The National Science Foundation is interested in creating texts that are shorter, contain core concepts only, and allow students to get more specific information from other sources. Most scientists would say that content is not as important as process, but students need terminology and fundamentals as a base and a "hook." Scientists disagree on the amount and balance of content and concept, however. Meaningful assessment is difficult, and most instructors do not know how to assess beyond content.

Career preparation. BMB is good preparation for several careers, but advising is often absent. Precollege teaching is an especially important career path, but it is also one made difficult 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 postbaccalaureate years or summer workshops.

As for all teaching programs, there is a high burnout rate.

Assessment. We have not agreed on the standards for outcomes assessment or how to determine the benefits of a BMB degree for undergraduates. The difference between the BS and the BA complicates the analysis; so too does the fact that many students take time off between college and graduate school, which makes it difficult to attribute success or failure to undergraduate preparation. Until we find effective ways to assess skills, as opposed to content, we cannot know whether 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.

Undergraduate research

The one clear finding of this study is that undergraduate research is regarded as centrally important to the preparation of scientists. The ASBMB recommendation that programs be designed to ensure a solid foundation of coursework that allows students to go on to a meaningful research experience may seem straightforward, but there is much uncertainty and even disagreement underlying it. What constitutes a "meaningful" experience? How long should it last? Must the project have outside funding or result in peer-reviewed publication? If the experience is defined as an extended period lasting one year or more, and if we expect publication-quality research, then there will be a shortage of space to accommodate all BMB majors in faculty labs.

The reported learning gains from a research experience have been clearly documented (Seymour, et al. 2003; Lopatto 2003). Some of the gains are closely connected to specific scientific skills and knowledge, such as learning lab techniques, understanding the primary literature, and interpreting results. Others are more generalizable and fit well with the AAC&U categories, such as understanding how knowledge is constructed, developing oral and written presentation skills, and learning ethical conduct. Still others—tolerance for obstacles, learning to work independently, self-confidence, and clarification of a career path—relate to student development.

When a full research experience is not possible, can students gain these skills in other ways? Our working group thought not, but a recent study suggests that at least some of the desired skills can be acquired from "research-like" courses (Lopatto 2006). 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 designed by students, opportunities for students to become responsible for part of a project, and opportunities for students to critique the work of their peers. With regard to the skills involved in interpreting results, analyzing data, reading primary literature, and communicating orally, students reported gaining at least as much—and occasionally more—from courses that score high in these activities as they gain from research experiences. On the other hand, students with a summer or more of research experience reported greater gains in terms of readiness for more advanced research, understanding how to approach real problems, lab techniques, and independence. Research-like courses may be good preparation for a "real" research experience, but they cannot serve as a substitute.

The BA/BS question

Those of us at liberal arts colleges, which produce a disproportionate number of PhDs in the sciences, began this study by assuming that the broad skills gained with a BA would be highly valued by graduate schools and employers. Some of us were surprised and dismayed to learn that depth in the discipline is valued over breadth. Because they equate "liberal education" with "liberal arts education," many scientists (and other academics) do not see its relevance to their institutions and disciplines. Yet as the AAC&U definition of liberal education makes clear, a liberal education can occur at all types of colleges and universities.

We need to articulate those elements of a liberal education that are essential for scientists operating in society, and then see how they fit into the BA-versus-BS divide. Students can be prepared by either degree for different career paths, but they need strong advising. Institutions that grant only the BA should make clear to students what courses—including research experiences—they will need if they intend to pursue further study in the field. Employers and graduate faculties should be made aware of the broad education of liberal arts graduates. Studies have shown that alumni of liberal arts colleges quickly overcome any short-term deficit they may have in preparation for graduate school, and that their strong communication and critical thinking skills give them a long-term advantage.

Pedagogy

We need to publicize broadly the innovative and effective pedagogies that are already in use within 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. Biology and its subdisciplines have lagged behind the physical sciences, perhaps because it is more difficult to articulate core concepts. However, several programs that support biology education reform have been funded by the National Science Foundation. Moreover, the American Society for Microbiology manages a research "residency" designed to develop understanding of evidence-based research in biology education and to help educators develop assessment tools for student learning.

There are already many examples of effective approaches to teaching biochemistry that employ active learning, including problem-based learning (PBL), process-oriented guided inquiry learning (POGIL), peer-led team learning (PTL), Just-in-Time Teaching (JiTT), and the case-study approach. All these are based on research about how students learn, and all 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 creating excitement about the discipline, our survey data show that most courses are still taught in this way.

It is important for participants in faculty development sessions to be exposed to practical ideas for teaching, student learning, and curriculum design, and that the ideas are implemented successfully. Presenters should have knowledge of science as well as knowledge of educational methods and theory. Even when convinced of the need for new teaching methods, scientists still need assistance in implementing changes in their own courses. The sessions should include workshops in which colleagues participate actively in applying the educational ideas to some aspect of their own teaching, assessment, or curricular materials. The workshop should end with a short-term evaluation and include longer-term follow up. Assessment is another tool for promoting the development of better pedagogy and teaching scholarship. Once instructors create or adopt assessments 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 problematic separation between faculty whose main focus is research and faculty 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 the academy, 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 one that could be made more available to interested faculty who teach undergraduates at all types of institutions.

Teagle Working Group Members

The American Society for Biochemistry and Molecular Biology (ASBMB) Working Group included the following members: Trevor R. Anderson, University of KwaZulu-Natal (South Africa); J. Ellis Bell, University of Richmond; Judith S. Bond, Penn State College of Medicine; Rodney Boyer, Hope College; Robert A. Copeland, EpiZyme, Inc.; Barbara Gordon, ASBMB; Nicole Kresge, ASBMB; Peter A. Rubinstein, University of Iowa Carter College of Medicine; and Adele J. Wolfson (chair), Wellesley College.

Working Group Recommendations

As part of the Teagle Foundation initiative on the relationship between the disciplines and undergraduate liberal education, the American Society for Biochemistry and Molecular Biology Working Group issued a series of specific recommendations for improving the biochemistry and molecular biology majors. The recommendations can be found in the full report of the working group, which is available online at www.teaglefoundation.org/learning/publications.aspx.

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

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In addition to the effective teaching of courses in the majors, we sought information on nonmajor courses with BMB content. One-semester biochemistry courses intended for premed or other science students are subject to many of the same pressures discussed above—content versus skills, lecture versus active learning. However, there are very few courses for nonscientists, 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 there are integrated introductory science courses that begin with large interdisciplinary problems before drilling down to basic principles. We encourage the BMB community to share examples of such courses and evaluate their effect on both student learning and recruitment into the major.

Assessment

Quite apart from the recent emphasis on assessment by granting agencies and accrediting bodies, it is obvious that cycles of innovation, assessment, evaluation, and redesign are as much a part of education as they are of scientific research. The challenge is to find assessment tools that provide real information about student learning and that 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 these measures, as long as they are carefully designed and are not used just to produce a student grade. Several AAC&U publications outline the types of assessment that address student gains in each of the skills categories discussed above. We also recommend that instructors and programs use the "liberal education scorecard" (Wick and Phillips 2008) to determine how elements of liberal education are balanced within their courses and majors.

Changes to the recommended curriculum

The skills included in ASBMB's recommended curriculum are indeed the ones considered essential by the membership. As we examined the relationship between these skills and those identified by AAC&U, some gaps became apparent—particularly 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 including "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. □

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