A revolution in biochemistry and molecular biology education informed by basic research to meet the demands of 21st century career paths

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The National Science Foundation estimates that 80% of the jobs available during the next decade will require math and science skills, dictating that programs in biochemistry and molecular biology must be transformative and use new pedagogical approaches and experiential learning for careers in industry, research, education, engineering, health-care professions, and other interdisciplinary fields. These efforts require an environment that values the individual student and integrates recent advances from the primary literature in the discipline, experientially directed research, data collection and analysis, and scientific writing. Current trends shaping these efforts must include critical thinking, experimental testing, computational modeling, and inferential logic. In essence, modern biochemistry and molecular biology education must be informed by, and integrated with, cutting-edge research. This environment relies on sustained research support, commitment to providing the requisite mentoring, access to instrumentation, and state-of-the-art facilities. The academic environment must establish a culture of excellence and faculty engagement, leading to innovation in the classroom and laboratory. These efforts must not lose sight of the importance of multidimensional programs that enrich science literacy in all facets of the population, students and teachers in K-12 schools, nonbiochemistry and molecular biology students, and other stakeholders. As biochemistry and molecular biology educators, we have an obligation to provide students with the skills that allow them to be innovative and self-reliant. The next generation of biochemistry and molecular biology students must be taught proficiencies in scientific and technological literacy, the importance of the scientific discourse, and skills required for problem solvers of the 21st century.

Establishing the foundation

For many biochemists and molecular cell biologists, the foundations driving interests in biology were immediately experiential. Most young children watch seeds sprout, plant a small garden, or conduct the celery experiment with colored water; some may make a pH indicator from purple cabbage or help deliver a calf or a litter of puppies. With such experiences, I always had questions about natural things—mostly biology, many not immediately answered—and thus required a visit to the local library or taking a dusty college book off the shelf in the living room. By middle school, interests grew, and learning about and drawing atomic orbitals was nothing short of fantastic. The subsequent foundations in math, chemistry, physics, and biology in high school were routine and lacked the excitement from earlier instructors with one exception. As a senior and taking now what would be called AP Biology or AP Chemistry, there was immersion with hands-on activities that included everything from pH curves and enzyme assays to animal dissections coupled with active discussions by teams of students of how and why. This was the foundation that established interests, thus setting the stage for my decisions and programs of study in college.

As an undergraduate student in the mid-1970s, I immediately realized that basic research was fundamental in driving education in biochemistry and cell and molecular biology. The journal Cell had been established in 1974 and, along with more established journals including the Journal of Biological Chemistry, Journal of Cell Biology, and Biochemistry, served as a platform linking cutting-edge research with teaching a sophomore-level cell biology course and extending to biochemistry and biophysical chemistry in subsequent years. The use of primary literature, while tough, provided real-time information that was being integrated into foundational concepts. As so, following my sophomore year, it was time to join a research laboratory, which was initially daunting, yet in time, an independent research project was developed that along with a rigorous course of study in biology and chemistry was foundational for advanced studies.

Graduate school offered the opportunity to deploy many of the same strategies using primary literature while teaching cell and molecular biology laboratory and learning the value of teamwork. There was an immediate realization that one’s passion for cutting-edge science was not universal, and thus it was essential to develop strategies demonstrating how the use of a research article in a laboratory setting was approachable. It became important to ask: How do you teach a sophomore to read a primary research paper? Where does data come from, and how can it be interpreted? How can a team be more effective that a single individual in addressing a specific question? And how does that data yield new information to drive the field forward? What came from this two-year period was a basic understanding of balancing the need to understand a concept and coupling that information with cutting-edge research to further advance that concept.

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One of the highlights of being a postdoctoral research fellow in the early 1980s was working with undergraduate students with a keen interest in biochemistry and molecular biology. My research was addressing the mechanistic basis of fatty acid transport and linkages to fatty acid activation and oxidation in *Escherichia coli*. It was during this period that the real importance of teamwork in science at the bench became apparent and that undergraduate students were effective members of a team given the proper mentoring. The undergraduate students were involved in key aspects of the work that included cloning the gene required for fatty acid transport (*fadL*), defining both patterns of complementation and expression, and culminating with purifying the protein FadL and showing that it was localized to the outer membrane. Three of the five papers published as a postdoc included undergraduate authors (1–3).

These foundations are not unique, as most scientists have comparable experiences. They did however, guide my passion to link research with teaching and learning with the firm belief that biochemistry and molecular biology education is informed by basic research. These linkages are coincident with science (and, more broadly, STEM) education research addressing the importance of asking questions, designing and conducting experiments, collecting data, drawing conclusions, participating in scientific discourse, developing novel pedagogical tools, and communicating findings to advance the field. This experiential learning, as informed by science education research, also requires creating rubrics to establish goals and outcomes and to assess learning (4–6).

**Setting the stage to create the right balance in biochemistry and molecular biology education and cutting-edge research**

The Morrill Act of 1862 establishing land grant universities, including the University of Nebraska–Lincoln (UNL), was profound by promoting “without excluding other scientific and classical studies… the liberal and practical education of the industrial classes in the several pursuits and professions in life” (7). The training in biochemistry at UNL embraces the importance of broader practical instruction and the training of scientifically literate graduates, which is consistent with the view that higher education is the major engine for socio-economic development. The transformation of our programs of study in biochemistry began in earnest in 2010, beginning with the recommendations from the American Association for the Advancement of Science, the National Science Foundation, and the National Education Council found in seminal documents, including *Vision and Change in Undergraduate Biology Education: A Call to Action* (8) and *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future* (9). This transformation was also informed by pioneering faculty at the university, in particular that of the botanist Charles Bessey. Bessey was known for innovative teaching methods that followed his belief that education was to be informed by research (10). His teaching and research were experiential and included establishing the classification system for flowering plants that has become standard. The impact of his efforts continues to resonate in the Nebraska National Forest, the first artificial forest that began with his tree-planting experiments with his students and in the establishment of federal programs that funded modern agricultural experiment stations.

The efforts to fully integrate the undergraduate and graduate education and research missions in the Department of Biochemistry began with the development of guiding principles, which were founded with the understanding that what we do in research and teaching is to improve the human condition.

- **Commit to an uncompromising pursuit of excellence.** Commitment to excellence is the firm ethos in teaching and research and is reflected by excellence in undergraduate and graduate education, cutting-edge research, and the generation of knowledge that is world class.
- **Stimulate research and creative work that fosters discovery, pushes frontiers, and advances society.** The highest standards for advancing research must be sustained through extramural funds and publications in the highest-quality journals in biochemistry and the molecular life sciences.
- **Establish research and creative work as the foundation for teaching and learning.** Students pursuing a biochemistry and molecular biology degree must be afforded every opportunity to conduct high-impact research in faculty laboratories with funding from individual grants and institutional programs that support such research efforts.
- **Prepare students for life through learner-centered education.** Students must be guided and challenged in classrooms and laboratories to become independent in seeking the knowledge and skills required to become successful professionals in biochemistry, molecular biology, biomedicine, and related fields.
- **Engage with academic, business, and civic communities throughout the state and the world.** Interactions and collaborations in biochemistry extend beyond the walls of the university to colleges and universities within the state and around the world, and through engagement with the private sector it is essential to bring the products of research and teaching to consumers as a benefit to society.
- **Create an academic environment that values diversity of ideas and people.** The faculty and staff of the Department of Biochemistry at UNL embrace diversity and inclusive excellence as a fundamental core value.

**Establishing a scholarly environment where research informs teaching and teaching informs research**

The Department of Biochemistry at the University of Nebraska-Lincoln was formally established in its current structure in 1995. The major immediately became popular, especially for students wanting to pursue medical school. By 2006, the department had a number of high-impact and established research programs, yet as a small research-intensive unit, teaching was seen as secondary. I joined the department as Chair in 2008 with a highly productive and externally supported research program, continuing our efforts to understand the mechanistic basis of fatty acid transport. Our work had
progressed from a bacterial model and over a 23-year period had progressed to yeast, mammalian cell culture, and animal models (e.g. see Refs. 11–15). The attraction of leading biochemistry at UNL was that all fundamentals were in place; the challenge was to move the department into the 21st century by linking research and teaching in proactive ways through engagement and new faculty recruitment. At the time, the department had a robust graduate program with high-caliber students conducting cutting-edge research.

Three members of the biochemistry faculty were working in the biochemistry education research space at that time, but their efforts were not integrated with the traditionally research-intensive faculty (16, 17). This situation was not unique to UNL, as there are comparable challenges in the STEM fields throughout the country, many of which have resulted into two-tiered departments. To this end, there was a significant uphill battle that had to occur in moving faculty from the “talking head” in course delivery to active learning with full integration of teaching and learning with research. I had seen this in play out as an undergraduate student and knew the value of this linkage and how basic research informed teaching. Further, during the 22 years prior to assuming the leadership of biochemistry at UNL, my teaching was in both medical and graduate education, where integrating foundational research into teaching, including medical biochemistry, was an essential part of my approach. A number of issues at UNL began to coalesce, including the opportunity to hire a significant number of faculty and build a modern, high-impact Department of Biochemistry with strong research programs linked to teaching and learning and meeting the demands of 21st century career paths. This included hiring 19 new faculty members (2 joint) since 2010 to advance the biochemistry research and teaching missions. The challenges were to hire both strategically and deliberately to strengthen research and teaching and to establish a faculty with demographics that were shared by the student population. A central tenant in all of these efforts was one of inclusive excellence.

The initial challenge was to convince the “traditionalists” that teaching 21st century biochemistry and molecular biology the way they were taught was inconsistent with training a modern workforce with a biochemistry education at the core. Part of this first challenge was eliminated with retirements. The second challenge was to identify strategic needs within the unit that worked collectively to advance both research and teaching. I likened this challenge to being the conductor of an orchestra, where all parts are essential and where the whole was greater than the sum of the parts. If the violins were not in synchrony with the brass, the result would be catastrophic. If there were weaknesses in the percussion or woodwinds that needed to be addressed, this became the priority. As a department chair, I did not need to tell the faculty what to do but, like a conductor, had to establish the environment to achieve optimal collaboration and integration among the existing and newly recruited faculty, professional and technical staff, and students. This challenge was also mindful of linking research areas and programs both within biochemistry and with other programs for added strength and impact. It was also mindful of the changing face of modern biochemistry and molecular biology to be more quantitative, especially with the emergence of high-throughout data and systems biology. A final and important challenge was to make biochemistry a true academic home for nearly 400 undergraduate majors. This necessitated a careful review of the curriculum and the establishment of practices where students were engaged and mentored in their progression through the program over four years. This also required building a faculty that valued basic research in biochemistry and molecular biology that extended to teaching and learning. The result was a broad appreciation of the interplay between research that advanced teaching and learning and the development of novel pedagogical tools and basic research that generated new knowledge.

The environment that was established over a 10-year period was one of inclusive excellence and one that allowed the best ideas to come forward and be discussed and refined with many being implemented. During this same period, the research programs with highly talented graduate students and postdoctoral research fellows flourished, advancing programs in plant biochemistry, metabolic biochemistry, biomedical biochemistry, biophysical chemistry, and biochemical informatics. One key outcome of this excellence was the development of a graduate training program, supported by the National Institutes of Health, in the Molecular Mechanisms of Disease. The breadth of research in combination with changes in the teaching culture established a landscape required to advance the training of students for existing and emerging career paths.

Leadership, innovation, and team building

Leadership in any academic department requires a long-term vision, not simply maintaining the status quo and steering the unit. Like a conductor and their orchestra, academic leadership requires a clear understanding of the team, the measures of success, and how that fuels the vision. In biochemistry, the excitement of basic research and the generation of new knowledge is foundational. The hum of active research programs is contagious and spills into the hallways and seminar rooms where there is experimental planning, the sharing of data, and active discussions. As members of a biochemistry department not associated with a medical school, the graduate and undergraduate students in the laboratories and classrooms become part of the fabric and through a fully engaged learning environment, gain the requisite foundations for their chosen career paths.

A central component of leadership in biochemistry, especially in a research-intensive institution, is to lead by example and embrace the missions of the department. At UNL, this was the clear expectation of the faculty—in essence, leadership that understood the details of the interrelated academic missions by being in and coming from the trenches. Academic leadership in a research-intensive department cannot be equated with just being a unit administrator. Leading by example was crucial in building biochemistry and required maintaining a robust research program with undergraduate and graduate students (e.g. see Refs. 18 and 19), contributing to the teaching mission and team building. It also required continual engagement with the faculty, staff, and students and proactive discussions with
the deans and upper university administration. The balancing required was much like walking on a floor of marbles and meeting the needs and vision of the faculty using the resources available through the university.

In 2010-11 and again in 2016-17, the Department of Biochemistry had to complete formal academic program reviews. As is the case for most academic departments, both were initiated with a self-study, which culminated with guiding principles and strategic visions. My resolve was that these reviews be faculty-driven, and indeed this was the case. Both occurred at the right time in moving the department forward. The first was significant as it identified the challenges and gaps required to advance the research and teaching missions into the 21st century. The second built on the outcomes of the first and included a number of new faculty hires that were crucial in developing the Vision of Excellence 2017–2022 document that, while dynamic, has proven highly successful in meeting the challenges of a 21st century Department of Biochemistry. Following the first academic program review, key faculty hires were made that were largely directed to strengthening the research programs in redox biochemistry, biophysical chemistry, metabolic biochemistry, plant biochemistry, and systems biology and biochemical informatics. It became important at the time that a significant effort be made to advance biochemistry in teaching and learning. During this period and as noted above, the interplay between research that advanced teaching and the development of novel pedagogical tools and basic research that generated new knowledge became part of the departmental culture.

The 2016-17 academic program review was able to highlight the successes of the previous years and set the stage for the continued growth of the department with the understanding that research and teaching are interdependent and that strength in one provides strength to the other. During this period, the four-year curriculum had been modified to include biochemistry courses in each academic year, thus creating an academic home for the undergraduate students. There were expanded efforts to engage as many students as possible in basic research laboratory work in biochemistry and across campus in the larger molecular life sciences. In concert with these efforts, internal and external grants were awarded to members of the faculty to strengthen biochemistry teaching and learning—these grants were given the same high level of recognition as those supporting basic research. These efforts were coincident with strengthening a strong graduate program to include increased emphasis on the diversity of career paths. All of this was occurring in an environment that was driven by the faculty and from team building that was coming from within. The outcomes have been remarkable, with a level of faculty interaction in both research and teaching and, more specifically, a level of excitement linking the two. In addition to grants being awarded to support teaching and learning, four members of the faculty were awarded National Science Foundation CAREER grants in 2018 and 2019. These grants require outreach and education as central pillars of a cutting-edge research program. I remain convinced that these awards were successful in large part because of the environment established in the department that values research and teaching at the same level—this is an environment of inclusive excellence.

As the University of Nebraska celebrated the 150th year since its founding and the Department of Biochemistry its 25th year, the department was awarded the 2019 University-wide Departmental Teaching Award as one of the President’s Faculty Excellence Awards. The University of Nebraska system specifically recognized the tradition of pedagogical excellence through faculty engagement and innovation. There was praise for the department’s innovative educational programs that emphasize critical thinking, experimental testing, and molecular and computational modeling that are directly linked to excellence in basic research in redox biochemistry, biophysical chemistry, metabolic biochemistry, plant biochemistry, and systems biology and biochemical informatics. The department was recognized for transforming biochemistry education and developing lifelong learners, leading to a number of high-impact career paths. The linkage between research that advanced teaching and the development of novel pedagogical tools and basic research that generated new knowledge was the common thread creating synergy leading to strength.

Program of study, critical thinking, and importance of scientific discourse

With the modernization of the biochemistry undergraduate curriculum to meet 21st century career paths, as is the case in many programs throughout the country, student engagement in their learning through critical thinking has become an expectation. It is now the tradition of biochemistry at UNL to present a body of information in concert with asking where it came from and how it advanced the field. As noted above, the biochemistry program has been modified to cover all four years. These changes in the undergraduate biochemistry curriculum have been driven by the faculty and supported by grants from the National Science Foundation, the National Institutes of Health, and the Kelly Fund, which is an internal philanthropic fund that supports advances in teaching and learning. The fundamentals are taught, but with a high level of student engagement in current trends in research, thereby providing an important backdrop to add interest and applicability to the learning process.

Beginning as freshman, students are introduced to fundamental concepts stemming from the ASBMB accreditation core concepts (energy is required by and transformed in biological systems; macromolecular structure determines function and regulation; information storage and flow are dynamic and interactive; and discovery requires objective measurement, quantitative analysis, and clear communication) at the same time they are taking initial sequences in biology, math, and chemistry. Student learning is assessed through on-line concept inventories. Students write a position abstract using the tools of scientific discourse to argue for or against statements made on a product that claims to be scientifically or clinically proven. Finally, they write a short scientific paper based on suggested topics within the core concepts that requires mastery of PubMed, learning to write in their own words, and citations of at least three primary works using the Journal of Biological Chemistry format. These efforts are integrated with college planning and skills, goal setting, discussions of working in a
research laboratory and understanding the importance of teamwork in learning, and discussions of career paths.

As the biochemistry students progress through the curriculum as sophomores, they are introduced to the critical nature of biochemical data and in particular how it is generated, interpreted, and presented in a scientific publication. These efforts are completed in concert with more writing and the integration of the data analyzed with other related works. Students work individually and in groups of four, with the class size limited to 24. This approach, while demanding, generates much discussion and a clear appreciation of scientific teamwork. Our experience shows that students taking this course prior to taking the year-long biochemistry sequence have enhanced performance.

The third year of study includes a two-semester comprehensive biochemistry sequence that has evolved from being presented in a typical lecture style to one blending experiential learning and standard lectures. The challenge has been the delivery of such a biochemistry sequence with 300-350 students, including 70-80 biochemistry majors. Faculty that teach in this sequence have led efforts developing interactive learning modules using dynamic 3D printed models to allow students to visualize biomolecular structures. At present, three targeted learning objectives related to DNA and RNA structure, transcription factor-DNA interactions, and DNA supercoiling dynamics have been developed and accompanied by assessment tools to gauge student learning in a large classroom setting. Students had normalized learning gains of 49% with respect to their ability to understand and relate molecular structures to biochemical functions (20). The technologies developed are significant and allow students to understand macromolecular structure-function relationships and observe molecular dynamics and interactions (21). I am quite certain that additional innovative teaching technologies along these lines will be developed to enhance learning in this biochemistry sequence. An additional and highly innovative platform developed by biochemistry faculty, the Cell Collective, uses computational modules allowing students to gain first-hand experience in areas as diverse as cellular respiration and the molecular dynamics of the lac operon (22). These efforts break down the barriers common in a large classroom setting, allowing students to work in small groups to understand complex biochemical processes. The junior/senior laboratory sequence in biochemistry has been modernized and directly linked to ongoing basic research in faculty members’ laboratories. As students gain broad understanding of basic biochemical concepts, they become well-prepared for advanced training in biophysical chemistry and structural biology that includes hands-on experience using programs such as PyMOL. These later efforts are coordinated with literature reviews, problem solving, and group presentations.

As seniors, biochemistry students complete a capstone course in Advanced Topics in Biochemistry with different topics that range from Plant Metabolic Engineering and Trace Metals in Redox Homeostasis to Metabolons and Metabolic Flux and the Biochemistry of Starvation and Obesity. These classes are limited to 24 students with group discussions that culminate in writing an advanced scientific paper and presentations. A central aspect of this course centers on scientific discourse with active discussions addressing potential discordance of data stemming from different experimental approaches. One instructor uses peer review of the student manuscripts, which culminates with a compendium of papers in the student journal, *Advances in Biochemistry*, that is shared with the class and archived by the department. Although the topical areas differ by instructor, this course is assessed using rubrics that are common among all sections.

For the majority of UNL biochemistry majors, their participation in laboratory-based research is woven throughout the program of study. In addition, and importantly, each student is individually mentored throughout the program of study.

**Primary research and creative works and the balance to maintain excellence in the biochemistry curriculum**

The Department of Biochemistry at UNL has top-tier research programs with research expenditures of $9-10 million/year, the majority of which are externally supported by grants from the National Institutes of Health, National Science Foundation, USDA, Department of Energy, and private foundations including the American Heart Association and Michael J. Fox Foundation. Coupled with this strength in research is a university-wide and highly impactful undergraduate research program, Undergraduate Creative Activities and Research Experiences (UCARE), that supports students over two semesters or a summer. UCARE is funded in part by gifts from the Pepsi Quasi Endowment and Union Bank and Trust. The office of the Agriculture Research Division (ARD) also supports academic and summer research experiences for undergraduate students. UCARE and ARD students must identify a research mentor and write a research proposal that is peer-reviewed. In biochemistry, additional undergraduate research students are supported during the academic year and summer by funds from individual research grants. These students are guided through standard operating procedures in research, biosafety, codes of conduct, expectations for ethical research, finding the right graduate program, and assistance through the graduate school application process.

At any given time, there are upwards of 50 undergraduate research students in the Department of Biochemistry laboratory. In addition, an additional 80–90 biochemistry undergraduate students are in the molecular life science laboratory, ranging from those in the Departments of Chemical and Biomolecular Engineering and Chemistry to those in Psychology and Food Science and Technology. It is important to point out that many of these students begin working in a research laboratory in their freshman and sophomore years and continue through graduation. All of the undergraduate research students participate in two university-wide research fairs, which involve juried poster presentations. Many of these students present their work in national forums including the ASBMB Annual Undergraduate Research Symposium. In addition to these undergraduate research programs, the university hosts numerous Research Experience for Undergraduate (REU) programs that are directed to students outside the university for research-intensive experiences in the summer. For those with interests in biochemistry, there are programs in Redox Biology, Biomedical Engineering, Molecular Plant-Microbe Interactions, and Virology.

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*ASBMB AWARD ARTICLE: 21st century biochemistry and molecular biology education*

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Embedded within these high-impact research programs are graduate students and postdoctoral research fellows. At any given time, there are 30–35 Ph.D. students and an additional 30–35 postdoctoral research fellows. These laboratories provide cutting-edge research environments where undergraduate research students become members of research teams, much in the same way I did as an undergraduate student.

These research experiences for undergraduate students occur because all members of the biochemistry faculty (and others in the molecular life sciences) see this as part of their scholarly activities and as members of the academy. Whereas maintaining a high research profile is essential for our institution, the proactive engagement of undergraduate students is also part of the fabric of the department.

This brings me back to the orchestra. The conductor generally does not play an instrument, yet he or she occupies a unique space between the orchestra and the audience. The conductor must understand the dynamics that occur in that setting and set the stage to benefit both the audience and the orchestra. Orchestrating a research-intensive biochemistry department, like that at UNL, with nearly 400 undergraduate students has many of the same elements. The cutting-edge research in bio-physical chemistry or metabolism is part of the foundation. Initially, the students see such activities as the audience, many as freshmen as they are introduced to the discipline and asking the question of why study biochemistry with its demands. They see the latest papers published from the department faculty on electronic boards highlighting novel cutting-edge research. Like a student of the orchestra, they are introduced to a small part of what we call biochemistry, but with the clear understanding that this is only a part of the total. Many students may not be able to work in in a research laboratory due to a variety of circumstances. In these situations, they gain experience in a teaching laboratory that is designed to emulate basic research. In both situations, these students learn and grow, in both the laboratory and a classroom that is increasingly experiential. Through the integration of basic research and modern teaching, these students become members of the orchestra we call biochemistry. The leadership of modern programs in biochemistry and molecular biology must facilitate this process. Like the conductor, departmental leadership must understand all aspects of the orchestra and the audience, in essence research and teaching and learning. They must establish an environment where students are trained in the discipline to advance their chosen career paths. This is the balance of teaching and research that maintains excellence in the biochemistry curriculum.

The richness of this type of training environment cannot be understated. The biochemistry students at UNL have been highly successful as evidenced by co-authorship on research papers, presentations, and awards. Over the past five years, biochemistry students have presented their research at the ASBMB annual meeting, where they have had opportunities to talk with the leaders in the field. Several of our students received outreach grants from the ASBMB, including one to support the Science Olympiad. Locally, biochemistry undergraduate research students continue to receive top awards at the university-wide research fairs. A number of these students have extended their efforts through participation in activities outside the traditional mainstream of basic research. One example are biochemistry students who have participated in the International Genetically Engineered Machine (IGEM) program. Others have coupled study abroad programs with experiential learning in biochemistry and biomedicine. Prior to graduation, students meet with the department chair, individually or in small groups, to provide their assessment of the program —over the past five years, the feedback has been uniformly positive. Finally, and importantly, the majority of biochemistry students enter postbaccalaureate programs with a high level of success, ranging from graduate programs in biochemistry and molecular biology to medical school, law school, and allied health programs. Others enter the local biotechnology sector, and in several cases, these individuals have risen to leadership roles in a short time.

**Biochemistry and the nonmajor, engagement in K-12 education, and outreach**

Biochemistry interfaces with many life science and engineering programs, and through course offerings for nonmajors, the department continues to occupy an important niche in teaching these students. These efforts are essential to the vitality of the department and are essential parts of the orchestra. In many cases, the challenges are greater, as many of these students do not have the vested interest in the discipline and are taking biochemistry courses as part of their degree requirements. Nonetheless, members of the biochemistry faculty have been highly innovative in this space and are now using course-based undergraduate research experiences (CUREs) as part of these activities, both in large classroom and laboratory settings. In addition, full on-line versions for summer and continuing education students and blended learning approaches are also being fully deployed.

There are now significant efforts coming from the biochemistry faculty to engage students in K-12 education. Current efforts include discipline-based education research and science literacy programs leading to the development of novel pedagogical strategies with a specific focus on developing educational programs in the molecular life sciences for K-12 schools and nonformal learning environments. These efforts are advancing the department’s national leadership in youth education in the molecular life sciences, affording increased awareness of and interest in careers related to science. One area of particular interest is instruction in core biochemistry courses that serve the broader life sciences community, including delivery to nontraditional learners (e.g. on-line courses for continuing education).

As part of the culture of inclusive excellence and linking research to teaching and learning, the department continues to be active in science outreach efforts. These efforts may be more minor at the outset, but consider how elements within an orchestral program come together—the tympani or piccolo at just the right time and with the right amount of emphasis and impact results in an outcome far greater than the sum of the parts. These efforts are driven by the faculty that become involved in university-wide efforts to provide broad exposure of students, especially those from underserved communities, to
the importance and impact of modern science. Two programs hosted by UNL that are of special note, Upward Bound and Women in Science, include efforts led by biochemistry research–intensive faculty with a commitment to teaching and learning outside the traditional boundaries of the academy.

Importance of ASBMB accreditation and maintaining high standards of excellence for 21st century career paths

Undergraduate education is a fundamental priority of the University of Nebraska. The biochemistry faculty have developed an undergraduate academic program that is directed at providing the foundation required for careers in industry, research, education, engineering, health professions, or other interdisciplinary fields. The B.S. degree is reflective of the discipline as a whole and includes current advances from medicine to biotechnology. The philosophy underpinning the undergraduate biochemistry program is a curriculum that includes coursework in each of the four years of study, individual mentoring, and the requisite electives for modern career specializations. Central to this philosophy are pedagogical strategies that include discussions of current research trends in biochemistry in the classroom at all undergraduate levels. Finally, and as detailed above, the biochemistry program works to provide primary research opportunities for all undergraduate majors, beginning as early as first semester freshman, as part of their experiential learning.

The Department of Biochemistry’s undergraduate program was accredited by the ASBMB in 2016 for a full seven-year term. The move to have a fully accredited program was driven by the high standards expected in the program of study, ongoing program assessment through concept inventories, and increased national recognition (23–25). The assessment exam given each year has allowed faculty to identify areas of strength and weakness in the program of study. One outcome of this assessment was to develop a senior level course in Biophysical Chemistry and Structural Biology, which integrates core concepts of physical chemistry with a focus on basic biochemical mechanisms. Since the biochemistry major was accredited, the number of undergraduate majors has increased by nearly 20%. More recently, the department has deployed a second biochemistry track with increased emphasis on biochemical informatics, statistics, and computational modeling. Coincident with these changes, the department has recently built a Biochemistry Resource Center that provides a visible home for the biochemistry undergraduate and graduate programs and a facility with full audio-visual capabilities for individualized study, tutoring, and small group discussions that include course-based and research-based efforts.

The finale of a symphonic work comes when all of the parts are visible—and heard—and this collective has lasting impact. This is not the result of one individual but of the many and, as noted, requires leadership that allows the best in each part to come forward. This finale is played in the UNL Department of Biochemistry just prior graduation in May and December, where members of the faculty host a Graduation Celebration to honor individual undergraduate and graduate students and their accomplishments. This finale extends to the recognition of biochemistry juniors and seniors as ASBMB Honor Society (Chi Omega Lambda) members. From 2016 to 2020, 28 of our students were inducted into Chi Omega Lambda and received their cords as part of the Graduation Celebration. In May recognition of their scholarly achievements, research accomplishments, and outreach activities. A final highlight to this finale is the department’s ASBMB-affiliated Student Chapter, which interfaces with the basic biochemistry research programs through active discussions with graduate students and postdoctoral research fellows, contributes to new student recruitment, is involved in community outreach and philanthropy, and hosts programs in career planning. These types of efforts led to the UNL Biochemistry Club being recognized in 2017 as the ASBMB Outstanding Student Chapter.

Reflection

Can these successes be replicated at other types of institutions including larger state universities with large enrollments but fewer research-active faculty, those with less funding, or smaller colleges and universities with fewer students and faculty? The answer is a resounding yes. There are several key points leading to this success. The first is that the leader of a biochemistry and molecular biology undergraduate program must have the ability to assemble a highly dedicated team. She or he must recognize individual strengths within the team, facilitate discussion, and work within to advance the best ideas directed toward the success of the program. As I have indicated above, the leader is like a conductor, allowing members of the orchestra to be their best while assembling a final product that is greater than the sum of the parts. The second point is that members of the team must be dedicated to the breadth of a 21st century program of study in biochemistry and molecular biology. They must contribute their individual scholarship through novel ideas and approaches and be willing to take risks in the development and deployment of new pedagogy. And third, the leader of such a program must listen to all members of the team and be mindful that such efforts are not about them, but rather the greater good.

Colleges or universities with fewer research faculty should not see such successes as unobtainable. The nature of experimental inquiry is part of who we are—picking up the latest Science or Nature provides an immediate snapshot of highly impactful science. For those of us in biochemistry and molecular biology, time well-spent each week is with the Journal of Biological Chemistry, Biochemistry, and Journal of Cell Biology, to name only a few. We can take what is at the cutting edge of modern biochemistry and molecular biology and, with our team, integrate this information into the classroom. For me back in the mid-1970s, it was the integration of research into teaching that contributed to the key decisions driving my early career. Our collective efforts in advancing biochemistry and molecular biology education can be bolstered by concerted efforts to acquire external funds, especially through the National Science Foundation. Finally, it is important for leadership to partner with upper administration in the college or university and let them know the power of our discipline in
training students for the 21st century career paths. It has been this type of partnership at the University of Nebraska-Lincoln that has provided financial support to students along with faculty for their research and in the development of novel pedagogical approaches to advance biochemistry and molecular biology education.

Perspective

Twenty-first century programs in biochemistry and molecular biology must have a continuing commitment and dedication to the education of students resulting in their chosen career paths with high impact. These shared efforts require the firm ethos of the faculty to maintain an uncompromising pursuit of excellence, which is reflected in their commitment to teaching and learning that is directly linked to cutting-edge research and the generation of world-class knowledge. The biochemistry and molecular biology students must be well-prepared for life through learner-centered education. It is essential that they are guided and challenged in classrooms and laboratories to become more independent in seeking the knowledge and skills required to become successful professionals in biochemistry, molecular biology, biomedicine, and related fields. All members of a biochemistry and molecular biology faculty must embrace established research and creative works as the foundation for teaching and learning. In concert, it is essential that biochemistry students contribute to independent basic research projects, many of which result in national presentations and publications—in essence, learning by doing. The educational and research programs in biochemistry and molecular biology must be holistic and highly integrated in such a manner to advance modern research to inform the academic program development, which includes the deployment of novel pedagogical strategies. These collective activities are the orchestra of biochemistry and molecular biology with many interrelated and essential parts. This is the esprit de corps underpinning the interrelated academic missions of the Department of Biochemistry at the University of Nebraska–Lincoln, one of inclusive excellence reflecting the diversity and ideas and people as a fundamental core value.

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Abbreviations—The abbreviations used are: UNL, University of Nebraska–Lincoln; UCARE, Undergraduate Creative Activities and Research Experiences; ARD, Agriculture Research Division.

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