Int. J. Engng Ed. Vol. 22, No. 1, pp. 53–58, 2006
Printed in Great Britain.

0949-149X/91 $3.00+0.00

Building an Integrated Undergraduate Biological Engineering Program in an Agricultural and Biological Engineering Department: Incorporating the Student Perspective*

JENNA L. RICKUS
Department of Agricultural and Biological Engineering, Department of Biomedical Engineering, Purdue University, USA. E-mail: rickus@ecu.purdue.edu

Agricultural engineering is the only traditional engineering discipline in which biology and living systems have always played a major role. The emerging field of biological engineering, therefore, finds a natural home in agricultural engineering departments, many of which have recently changed their names to reflect their inherent and growing emphasis on biology. These departments are restructuring, or expanding to integrate focused biological engineering programs into their educational infrastructure. The goal is to create a new community of engineers who are savvy in the biological sciences and can engineer living systems. This paper discusses the challenges specific to building biological engineering programs in a historically agricultural engineering department at the undergraduate level and suggests a framework for meeting these challenges. The student perspective is emphasized and the author draws on personal experience as both a former student and a current faculty member in biological engineering. The recent efforts within Purdue University's department of Agricultural and Biological Engineering are used as an example and a backdrop for discussion.

Keywords: biological engineering; agricultural engineering; program development

'WHAT IS BIOLOGICAL ENGINEERING?' IS ONLY THE FIRST QUESTION

THE ACADEMIC COMMUNITY has essentially converged on a general definition of biological engineering (BE) [1] to be the integration of life sciences with engineering to design biologically based products and processes and to advance fundamental knowledge of biological systems, materials, processes, and organisms [2]. This definition extends from the molecular to the ecological scale, but carries some debate as to whether BE should be a science- or application-based discipline. While traditional engineering disciplines such as electrical, chemical, and mechanical engineering have applications in biological systems, a biological engineer is distinguished from others by possessing an extensive and broad knowledge of and experience in biology as well as an ability to apply more biological frameworks to understand complex systems [3, 4].

Much effort and discussion has focused on what the core competencies of a biological engineer are and in turn what the content of a biological engineering curriculum should be [4, 5]. Despite this, no single standard curriculum has emerged such that every graduating biological engineer has the same basic skill set.

While the topic of 'what is biological engineering?' has been extensively discussed in the literature and at conferences, the practical challenges of implementation have been ignored in the broader community and left to individual departments and institutions to sort out. These seemingly minor details turn out to have a dramatic influence on the student experience and could ultimately determine the success or failure of an educational program.

Undergraduate engineering students are navigating the path from childhood to adulthood and trying to identify their future roles in society while simultaneously undertaking intense academic studies. The highest priority of most students and their parents during these years is achieving a successful first step on their career path immediately following graduation. These students expect guidance and support from their academic program and instructors. From the perspective of a BE undergraduate student, the details of how their academic program is perceived, defined, and accepted by industry, by academics, by other engineering disciplines, and by society are extremely important. Students must present their résumé to hiring companies, interview for positions, apply to graduate schools, and generally

* Accepted 22 August 2005.

negotiate their futures with this perception either working for or against them.

From this point of view, 'what is biological engineering?' is only the first question. The second and equally important question is '*what is the role of agricultural and biological engineering departments in the education of biological engineers within the complete landscape of academia and industry?*' It is this question that will ultimately define the perception of agricultural and biological engineering programs. The answer will explicitly shape the immediate future of baccalaureate level graduates.

WHY AGRICULTURAL AND BIOLOGICAL ENGINEERING?

As a 17-year-old freshman engineering student at Purdue, I surprised myself and my parents by choosing agricultural engineering as my major. Despite growing up in Indiana, I had neither experience in nor desire to pursue agriculture according to what I *thought* agriculture was. How then did my choice of major occur? It happened because I was searching for a program within engineering where I could also study and apply biology. Agricultural engineering was the only established department that could offer both. A recruiting faculty member explained that agriculture is about living systems: plants, animals and humans. The evolution of agriculture as a science has led the field into areas of advanced technology including genetically modified organisms, nutriceuticals, advanced animal nutrition, biofuels, biosensors, biobased products, and food processing, all of which require detailed knowledge of molecular biology, biochemistry, physiology, microbiology, or cell biology. This relationship made sense only after it was explained. Due to my misconceptions about agriculture, I never would have come to the conclusion on my own.

This personal anecdote highlights the most significant challenge facing the establishment of biological engineering undergraduate programs within agricultural and biological engineering departments: *how does an ABE department communicate its vision of biological engineering to industry, prospective students, and parents?* This question is actually a cloaked version of the previously proposed question, as the vision must be developed before it can be communicated.

WHY DO WE NEED BIOLOGICAL ENGINEERING?

If communicating biological engineering's role within agricultural engineering is difficult, then how do we know that we need it? Human beings have an inherent drive to control and take advantage of any force, material, or entity that it is possible to manipulate. Manipulation and control require knowledge. Biology, particularly on the molecular and cellular scales, has experienced a recent proliferation in knowledge that has fueled the desire of humans to control it. Our society is influenced by a biological environment that sustains our existence and modulates our daily wellbeing and happiness. The food we eat, the illnesses we suffer, the landscape we enjoy are all part of the biological environment. Creating a better world by improving our food systems, natural resources, and communities has always been the mission of agricultural engineering. As biology advances, biological engineering is inevitable.

DOES THE 'AND' IN AGRICULTURAL AND BIOLOGICAL ENGINEERING MAKE SENSE?

Establishing the nomenclature for the relevant educational programs and organizational structures is at the heart of establishing and communicating a vision. A name is the tag by which all students, recruiters, and colleagues identify a program. The name should encompass the essence of the vision and be widely recognized.

As stated earlier, the conceptual definition of biological engineering is generally agreed upon. Disagreements arise, however, when trying to define biological engineering within philosophical and administrative frameworks that consider relationships to other disciplines. Now the nomenclature becomes difficult.

One point of view contends that biological engineering is a science-based engineering with subsystems that include 'applied bio-based engineering fields such as food engineering, agricultural, forest, bioresources, biomedical, and biochemical' [2]. If one accepts this framework, then, within an organizational structure, agricultural engineering, food process engineering, and environmental engineering (all major thrusts of education and research in many agricultural and biological engineering departments) actually belong under a larger biological engineering heading.

While logical when viewed as a snapshot of today's scientific landscape, this hierarchical framework generates confusion and discomfort among many when considered with historical and administrative perspective. The applied subfields have long-rooted histories, in contrast to the more newly conceived concept of biological engineering. In addition, when defined broadly (as it is here), biological engineering also includes areas such as biomedical engineering which are establishing themselves as independent departments at many universities [6]. Right or wrong, biomedical engineering and bioengineering are commonly viewed as synonymous and are two of the fastest-growing majors [7, 8].

Most institutions have resisted such an organizational structure and nomenclature because the historical roots and current strengths are too important to ignore. The applied fields have critical ties with industry and alumni that should not be severed. Because the newer concept of biological engineering actually evolved in part from advancements in agricultural engineering, most agricultural engineering departments and programs have changed their names to reflect both the historical foundation in agriculture and the fundamental foundation in biology [9].

CREATING AND COMMUNICATING THE VISION OF BIOLOGICAL ENGINEERING

Ironically, the same history and long-standing foundation in biology that make agricultural engineering departments ideal for building biological engineering programs are also the source of the most significant hurdles. The young students who will pursue biological engineering are likely to be different than former students of traditional agricultural engineering [10]. Many of these new students will have no interest in traditional agriculture and will not come from farming backgrounds. They will consist of a more diverse population and include those with more urban and industry-centered goals. The recruitment of such students to an undergraduate program will require a clear and powerful vision of biological engineering that is not confused by fears of losing historical strengths. Rather, we must embrace the future of agriculture with confidence.

Communication of a vision is most powerful when it is simple, logical, and exciting. Because agricultural engineering is not ubiquitous, varies in focus across institutions, and is even eclectic within institutions, communicating a clear vision is challenging. When surveying the names of member departments and programs participating in the American Society of Agricultural Engineers (ASAE), one sees a wide variety of attempts to communicate the new emphasis on biology, including agricultural and biological, biological and agricultural, biosystems, biological systems, bioresource, and agricultural and biosystems. Biological engineering programs within the agricultural community would benefit significantly by the creation of a unified vision for undergraduate education.

DISASSOCIATING RESEARCH-LEVEL SPECIALIZATION FROM UNDERGRADUATE EDUCATION AT THE DEPARTMENT LEVEL

The biological engineering faculty and research programs at different universities will inevitably have a wide variety of expertise and areas of specialization. Unlike graduate programs, undergraduate programs do not necessarily need to be defined by those same areas. Educating undergraduate biological engineers by means of an application-independent method will help to move the discipline towards a more standard meaning of what a B.Sc. biological engineer is and can do. Students will have an easier time communicating their capabilities to potential employers, and educational programs will have an easier time communicating their goals to prospective students.

SOLVING THE STUDENT IDENTITY CRISIS BY FOSTERING COMMUNITY

There is not yet one central dominant professional society for biological engineers. In fact, there are few established career paths for biological engineers. There are also few existing industry managers with degrees in biological engineering. Such an environment leaves students to forge their own paths. While this situation presents an exciting opportunity, it can also be a source of anxiety and frustration. Students should not be left feeling that they are finding their way in isolation.

Students suffer if their academic program does not have a clear mission and defined role [8]. Through their interdisciplinary coursework, BE students interact with students in established disciplines such as biology and traditional engineering that do have a clear mission and role. In this environment, BE students can be left with the feeling of not belonging to any professional community.

It is, therefore, the responsibility of biological engineering faculty, programs, and departments to create a community for biological engineering students. This community must include fellow students, graduate students, faculty, alumni, and industry partners. A solid community will provide support for students, create a sense of belonging and purpose within society, and foster the crucial interpersonal relationships and industry networks that will facilitate successful career paths.

A CONFLICT BETWEEN TRADITIONAL BIOLOGY AND TRADITIONAL ENGINEERING? A MORE NARROW GAP FOR AGRICULTURAL ENGINEERS

It is sometimes argued that engineering has traditionally interfaced with sciences such as chemistry and physics that are based in first laws, and that biology is a science of observation that lacks first laws [11]. On the surface this statement appears valid; however, closer inspection reveals that this statement is an oversimplification.

The central dogma and cellular theory are examples of biology's version of first laws. These theories state fundamentals that are the foundation for all biology: living systems use DNA, RNA, and proteins to store, replicate, and express information and living systems are composed of cells as the fundamental unit of life. The difference for biology is that there are few universal constants or simple mathematical relationships. Regardless, these ideas frame all current experimental and theoretical work in biology and biological engineering.

Biology has historically been out of reach of undergraduate engineering, because biology is a science of behaviors that are emergent properties of systems. These systems are complex in space and time and are based on nonlinear interactions [12]. Engineering, on the other hand, tends to deal with well-defined systems that can be simplified and described quantitatively by governing equations. At the undergraduate level, biology has avoided mathematics, engineering has avoided complexity, and the two, therefore, had not met until recently.

The exception to this generality has been agricultural engineering. Because the problems the field has faced have always contained unavoidable biological components, agricultural engineers have been forced to deal with them. Food process engineering is a good example. In this field engineers must apply engineering fundamentals (thermodynamics, fluid dynamics, transport, and physical properties), similar to those a chemical engineer might use, to biological food materials that are heterogeneous, of complex and variable composition, nonlinear, and dynamic.

LIMITED TIME IN A FOUR-YEAR PROGRAM

When creating a new curriculum that is a blend of two disciplines, the tendency is to approach the problem by selecting the essential components of each traditional area and piecing them together into a new plan of study. With this approach, one quickly determines that all aspects are essential and that it cannot be completed in four years. The reality is that biological engineering students cannot learn all of biology and all of engineering in a four-year engineering program. So what areas of biology do we cut?

I argue that this view is the wrong way to approach the integration of biology into the curriculum. Undergraduate biological engineers should have extensive biological background, but should not be specialists within biology. Engineers excel at taking on a new problem and quickly identifying the key pieces of information that need to be obtained. A well-trained biological engineer should be flexible enough to jump into almost any area of biology and contribute to the problem a possible solution or design of a system. A biological engineer should, therefore, have, at minimum, an exposure to and appreciation of molecular biology, biochemistry, anatomy, plant and animal physiology, cell biology, microbiology, and ecology. In addition, the student should possess more complete competencies in the conceptual fundamentals and basic lab skills associated with two or three of these areas.

In order to accomplish this, one needs to re-evaluate how students learn biology. Students need not take a complete course in each area, but rather certain biological concepts can be integrated into engineering courses. Likewise certain engineering concepts can be integrated into biology courses. This, of course, will require significant collaboration on the part of faculty in both disciplines to accomplish this. Biologists need to be a part of the discussion.

Another alternative to solving the biology competency problem is establishing the option of dual degrees. At Purdue, undergraduates in the biological and food process engineering program can also pursue a joint bachelor's degree in either biochemistry or pharmaceutical sciences as a five-year program. This has been a rather successful path for many (including the author) highly motivated students who want more extensive training in a focused area of biology that is directly applicable to the biotechnology industry. The acquisition of a degree in science as well as engineering facilitates opportunities in a wider sector of industry and provides the students with truly dual training. Of course, not all students wish to pursue such an intense five-year program, and this option does not replace the need for the four-year program.

TWO MODELS OF INTERDISCIPLINARY EDUCATION: INTERDEPARTMENTAL FUSION VERSUS INTRADEPARTMENTAL FUSION

The suggestion of integrating biology into engineering courses should not be taken to the extreme. The result is no longer an interdisciplinary program where students are well versed in two culturally distinct worlds, but rather a new isolated program. Benefit can be claimed from a student learning biochemistry from a biochemist. The reality is that graduating biological engineers will be interviewed by people who were trained in more traditional unidisciplinary programs. Students must be viewed by these individuals as fully competent and not as a partial engineer or a partial biologist. Students can battle this possible perception by being comfortable with the culture and language of both worlds, a trait which only develops from spending time in them.

The importance of being fluent in the language, concepts, and approaches of both engineering and biology is not a new idea and is commonly included as essential in creating a successful biological engineering program [13]. This idea may seem contradictory to the earlier suggestion of efficiently integrating biology into engineering courses. The resolution is simple.

The blending of the two approaches will enable the simultaneous goal of synergy and dual exposure. Biology must be both integrated into engineering courses and taught in a more pure form. Conversely, engineering should be integrated into biology courses. This second idea is a concept that is rarely addressed in curricula design discussions. It is straightforward to integrate biology into engineering courses by simply using biological examples in lecture, homeworks, and student projects. Incorporating engineering concepts into biology courses requires a bit more creativity and collaboration, but it is possible.

One of our biological engineering initiatives at Purdue includes the creation of a new course in quantitative cell biology that complements a more traditional cell biology lecture course. Engineering concepts from thermodynamics, kinetics, process control and complex systems are reinforced or introduced through interactive computer-based learning modules that also teach biological fundamentals, including ion transport [14], protein expression, and phylogeny [15].

ADVANCED DEGREES: A REQUIREMENT?

Biological engineering should be a science-based discipline and should train undergraduate students as biological generalists. One might interpret this to mean that biological engineers will be 'unfinished' as this stage and will require on-the-job training or an advanced degree [13]. This statement, however, could be argued for all engineering disciplines today, not just biological engineering [16]. Most likely a large number of biological engineering students will pursue graduate school [10], but not all will choose to.

If students with master's degrees are truly better prepared to meet the needs of industry, then, rather than viewing graduate school as a requirement, undergraduate education should be re-evaluated. Possibly some of the research- and laboratory-based skills that are typically reserved for graduate school should be incorporated into undergraduate programs. This restructuring does not have to be accomplished through more classes but rather through a reform of current ones. Introducing strong experiential learning components to existing courses will likely be an important aspect of educating BE students that are well prepared for industry.

IN SUMMARY

A number of practical, social, philosophical, and historical challenges need to be addressed when building a biological engineering program within an agricultural and biological engineering department. This paper intended to highlight these challenges and suggest a framework for addressing at least a few of them.

Based on personal experience as a student, an engineer in industry, and a current faculty member, the author makes the following recommendations for building biological engineering undergraduate programs in an agricultural and biological engineering department:

- build a strong program vision that considers and defines its role in society, its relationship to other disciplines, and its relationship to other biological engineering programs;
- effectively communicate that vision to students, future students, parents, and industry representatives;
- differentiate the program from other areas of engineering by establishing a strong foundation in biology and integrating new toolsets for complex systems;
- build a science-based program that is flexible and, in the long term, not linked to any one bio-based industry that may or may not prevail;
- build a program and strategy that actively targets particular industries and specific jobs for its graduates in the short term;
- target the strongest students to become the future industry leaders;
- build a strong community of students, faculty, and industry; and
- embrace leading-edge technology and experiential learning in the undergraduate curriculum.

At most, the author's opinions are a starting-point for continued discussion and it is hoped that, from this discussion, the agricultural engineering field will formulate a unified vision for undergraduate education.

REFERENCES

1. O. J. Loewer, American Society of Agricultural Engineers, Resource Online, *A History of Biological Engineering from an Agricultural Engineer's Perspective*, (1997) (http://www.asae.org/resource/ojloewer.html).
2. J. H. Dooley, Biological engineering definition, in *Encyclopedia of Agricultural, Food, and Biological Engineering*, Marcel Dekker (2003), pp. 60–63.
3. R. E. Ulanowicz, Drawing engineers out of the machine, *Proceedings of the 10th Annual Institute of Biological Engineering: Biology-Inspired Engineering Frontiers*, Athens Georgia (2005).
4. J. H. Wells and T. A. Taylor, First principles in biological engineering education, *Resource* (1996).
5. J. Dooley, The Institute of Biological Engineering, IBE 2001 workshop on DNA of biological engineering: Defining the body of knowledge for the discipline, BE Core Concepts (2001) (www.ibeweb.org/teaching/dna/index.html).
6. The Whitaker Foundation, *The Whitaker Foundation 2004 Annual Report: Biomedical Engineering and the Medical Applications of Nanotechnology* (2004) (http://www.whitaker.org/04_annual_report/ar2004.pdf).

7. M. Loftus, Bioengineering has become one of the fastest growing majors, *PRISM*, **14**(3) (2004).
8. D. W. Gatchell and R. A. Linsenmeier, Undergraduate biomedical engineering curricula: Recommendations from academia and industry, *Proceedings of the 10th Institute of Biological Engineering Annual Meeting: Biology-Inspired Engineering Frontiers*, Athens, Georgia (2005).
9. American Society for Engineering Education, *2004—Participating Programs: Undergraduate Engineering* (2004) (http://www.asee.org/about/publications/profiles/upload/10_undergrad_programs04.pdf).
10. R. L. Bengtson, *Louisiana State University's Biological Engineering Program*, 2003 ASAE Annual International Meeting, Las Vegas, Nevada (2003).
11. W. Rosalind, Education for the profession formerly known as engineering, *Chronicle of Higher Education*, **49**(20) (2003), p. 2.
12. S. G. Hall and M. Lima, Problem-solving approaches and philosophies in biological engineering: Challenges from technical, social, and ethical arenas, *Transactions of the ASAE*, **44**(4) (2001), pp. 1037–1041.
13. A. T. Johnson and W. M. Phillips, Philosophical foundations of biological engineering, *Journal of Engineering Education* (1995), pp. 311–318.
14. M. Verleger, H. Diefes-Dux, J. Rickus and S. Schaffer, Drag the green ion: An interactive online quantitative cellular biology learning module, 2005 American Society for Engineering Education, Portland Oregon (2005).
15. M. Verleger, H. Diefes-Dux, J. Rickus and S. Schaffer, An online bioengineering learning module: Phylogenetic relationships, 2005 American Society for Engineering Education IL/IN Sectional Conference, DeKalb, IL (2005).
16. E. T. Cranch, The next frontier in engineering education: The master's degree, *Journal of Engineering Education* (1994).

Jenna Rickus recently joined the Purdue University faculty as an Assistant Professor in the Department of Agricultural and Biological Engineering and the Weldon School of Biomedical Engineering. She is dually trained in biology and engineering, with a B.Sc. in Agricultural Engineering and a B.Sc. in Biochemistry, both from Purdue University, as well as a Ph.D. in Neuroengineering from the University of California Los Angeles. Dr. Rickus teaches three multidisciplinary courses on biosensors, nonlinear dynamics in biological systems, and quantitative cell biology. In these courses she teaches a diverse group of undergraduate and graduate students. Her research interests involve the mimicking and modeling of biochemical and cellular systems for engineering cell-based devices and materials.