2006-2342: REDEFINING A BIOLOGICAL ENGINEERING UNDERGRADUATE CURRICULUM: PROFITS, PITFALLS, AND PRACTICALITY

David Britt, Utah State University

David Britt is an Assistant Professor of Biological Engineering. His research interests focus on renewable polymers, molecular imprinting, and biofilm formation. He is currently the Principle Investigator for an NSF Planning Grant in the Department Level Reform Division.

Mark McConkie, Utah State University

Mark is currently a doctoral student in the department of Instructional Technology at Utah State University specializing in the representation of declarative knowledge for systems that improve recall of textual material, and also the field of open content.

Timothy Taylor, Utah State University

Timothy Taylor is a Principal Lecturer of Biological Engineering. His recent research has focused on cellular physical property changes to plant cells grown in suspension culture with processing. He teaches classes in the areas of engineering quantification of biological processes and biological engineering design. He is currently a Co-Principle Investigator for an NSF Planning Grant in the Department Level Reform Division.

Redefining a Biological Engineering Undergraduate Curriculum: Profits, Pitfalls, and Practicality

Abstract

Over 10 years ago Utah State University introduced the Biological Engineering program as a replacement to the Agricultural Engineering program because of declining enrollment. In reality, however, not much had changed to the program but the name, and consequently, initial enrollment gains began to erode. With the addition of dedicated biological engineering faculty and serious commitment to a new curriculum, the Biological Engineering program is now growing and joins a number of other programs in the country based on biology, with its breadth of applications, as a science-based discipline. We describe here the history of our transition and highlight our emphasis on the alignment of planning at the discipline, curriculum, and course levels.

Introduction

The discipline of biological engineering has been emerging for nearly thirty years[1] with a rapid increase in departments and programs under various names adopting curricula in the past ten years. The programs that were derived from agricultural and natural resources backgrounds traditionally have degree names such as biological engineering, biological and agricultural engineering, biological systems engineering, or bioresource engineering. Those that have evolved in conjunction with human medicine are generally called bioengineering or biomedical engineering. In the past there was a fairly clear distinction between programs that had emerged from agricultural and natural resources backgrounds and those that were developed around applications for human medicine. These differences are blurring as faculty in both types of programs and faculty in other programs realize that biological engineering is becoming a discipline based on a fundamental science foundation rather than just an application based field. Theories and techniques are not limited by traditional research boundaries and instead can be applied to a wide variety of biological based areas.

As biological engineering programs such as the one at Utah State University develop that attempt to bridge the gap between these traditional programs by representing the full breadth of potential education and research interests in the discipline of biological engineering, questions and issues arise about what should be included in the curriculum of a biological engineering undergraduate degree. Addressing and redefining biological engineering curriculum content also presents a prime opportunity to address the status of undergraduate engineering and science education teaching practices. Because biological engineering encompasses such a broad area, the challenge arises of how to create a broad and flexible engineering curriculum without compromising fundamentals, and doing so in a way that incorporates what we have learned about effective educational practices. We outline here critical steps we have taken following a departmental name change and point out the potential profits, pitfalls, and practicality of dramatic curricular restructuring. We will describe our efforts as they apply to the field of biological engineering in general, the department's overall curriculum, and specific educational / instructional activities.

Background

During the early 1990's enrollment was decreasing in agricultural related engineering programs around the United States. Utah State University was no exception, with a total Agricultural Engineering undergraduate enrollment approaching ten students. In response to the decline in enrollment and to address the emergence of the biological engineering degree programs around the country the Biological Engineering degree program was created in 1993. Since then, it has been the fastest growing undergraduate engineering discipline on campus, growing from 20 students in 1998 to 85 students in 2004 (Figure 1). The new curriculum was based on an emerging set of recommendations from a project funded by the United States Department of Agriculture to study curriculum requirements for biological engineers[2]. These recommendations addressed the concept of a biological engineer from an agricultural and natural resources perspective. Many departments that adopted the recommendations and changed their degrees to biological engineering struggled at first due to a lack of a complete pedagogical change in the departments. Often the departments changed the degree name and added a biology course or two to the curriculum, but failed to fully embrace the full breadth of what biological engineering meant to the students that were attracted to the programs.

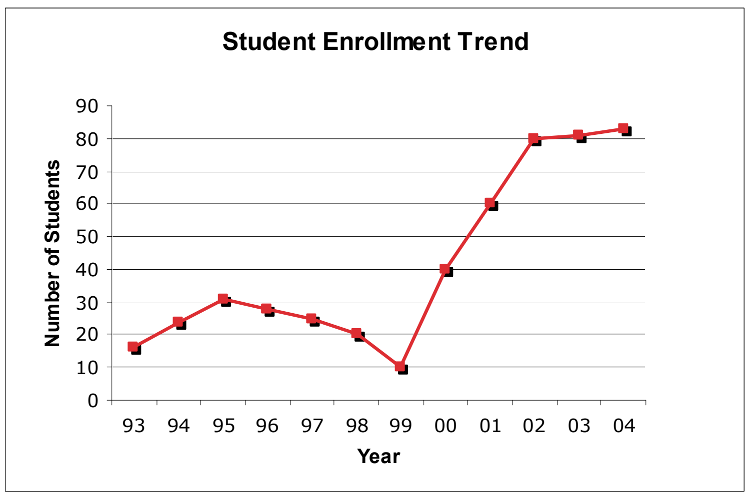

Figure 1. Biological Engineering undergraduate enrollment at Utah State University from 1993 to 2004.

By the mid 1990's a serious discussion was occurring among educators to define biological engineering and establish first principles required for curriculum development and content[3,4]. From these discussions, a broader and more inclusive view of biological engineering was growing among many of the departments that had developed during this period. From a biological perspective it could be seen as a natural progression or evolution of the discipline. Once the concept of the discipline of biological engineering had emerged it was going to grow and evolve into all possible niches.

At the same time biological engineering programs were developing from agricultural and natural resources engineering programs, biomedical engineering and bioengineering were evolving primarily from electrical and mechanical engineering programs to fill the application based need in human medicine. The development of the discipline of biomedical engineering was aided by the Whitaker Foundation's support of faculty and department establishment grants.

As biomedical engineering research grew and diversified, faculty realized that the techniques and tools they were developing could be applied to many areas of biology beyond human medicine. Massachusetts Institute of Technology (MIT) established the Biological Engineering Division in 1998[5]. At MIT it was argued that the fundamental difference between biological engineering and biomedical engineering was the former is "discipline" based and the later is "application" based. At approximately the same time California Institute of Technology (Caltech) was establishing a bioengineering division, with the purpose of pursuing the breadth of biological engineering[6]. Once again, the natural evolution of the discipline was evident as the broader concept of biological engineering was emerging from a second field.

The most recent emergence in the field of biological engineering education had been the entrance of the chemical engineering discipline. With a drop in student numbers many chemical Engineering departments have changed their names to chemical and biological engineering to appeal to a broader number of students. These departments have added the name, but generally have not defined what the name change means to the core curriculum of the departments. The American Society of Chemical Engineering (AIChE) has proposed the formation of The Society for Biological Engineering. The change in name of programs and the creation of a society will require an assessment and evaluation of the definition of a Biological Engineer.

Planning Education at Every Level: Discipline, Curriculum, and Course

The approach we have taken in restructuring the curriculum has been to start with a view of what is happening with biological engineering education standards at the discipline level. As these standards emerge we are playing an active role. In parallel, but with more direct control, we are restructuring our own curriculum for greatest efficiency and impact. With a clear idea of what our curriculum will be from a macro level perspective, we are in a good position to create courses across and the breadth and depth of biological engineering content in a balanced, integrated manner. Even though discipline standards, department curriculum, and individual courses may develop at different rates, and not in a linear fashion, our goal is to explicitly define the relationships between each level early so that as the discipline standards take shape we can ensure that our curriculum is updated, and focus our efforts in a continuous improvement process over time. Keeping the principle of alignment in mind, the next few sections of this paper will consider some of the profits and pitfalls associated with our efforts at discipline, curriculum, and course levels.

Defining the Biological Engineering Discipline

This activity looks outside of our program to the broader biological engineering community. Our hope is that this paper can add to and catalyze the already healthy discussion about what should constitute the core of a biological engineering education. Accreditation bodies and professional communities like the Institute of Biological Engineering, of course, play a critical role in this regard.

Profits (Discipline Level)

- *Standards guide curriculum and course development*. Without clear aims for a program, it is all too likely that a curriculum will resemble a patchwork quilt, where "one patch has nothing to do with the next patch, except that it is sewed to it….Curriculum often exists as disjointed clusters of content organized as particular items that frequently duplicate and / or conflict with other items."[7]

- *Definition of the discipline enables teaching quality to improve*. Frequent changes in the K-12 math curriculum in the United States is one example of how curricular instability leads to underachievement. As Anderson observes, "Teachers no sooner learn how to teach to one goal than they find that the curriculum goals have changed."[8]
- *Set guidelines keep a program in line with trends and needs in the field of engineering*. In other words, we are able to prepare engineers for the future as described by the Committee on the Engineer of 2020.[9]
- *A new name enhances undergraduate recruitment*. The enrollment trend at USU (Figure 1) tells an interesting story. A name change occurred in 1993 and was followed by a modest increase in enrollment. However, not much about the program had changed and as students realized this fact, the enrollment steadily decreased until about 1999 when new faculty were brought in and the biological character of the program began to truly take shape. Enrollment has since rapidly increased and appears to be equilibrating near 85 undergraduates. Biological engineering and related disciplines (e.g. biomedical engineering) usually enjoy a high degree of popularity[10], but as the story from USU illustrates, potential short term gains that can occur with a simple name change are not enough to ensure long term sustainability—in the end, the students will apply the "truth in advertising" act to all who augment their department name with a "bio" prefix.

Pitfalls (Discipline Level)

- *Overreaching*. Trying to standardize too much. Not only is this impractical but it is undesirable and will certainly result in a poor adoption rate. Each program should be able to specialize on the basis of its own faculty expertise, institutional charters, resources, and locale. One mold does not fit all situations. As an example, the Chemical Engineering Department at Montana State University (recently renamed to Chemical and Biological Engineering) will certainly leverage the expertise and notoriety of the Center for Biofilm Engineering, building a program around an existing core infrastructure. To address diversity in interest, four fields of specialization are listed in MSU's CHBE program: Bioengineering, Materials, Environmental Engineering, and Chemical Process Engineering. As accreditation will remain through Chemical Engineering, student specialization in one of these focal areas will be achieved, "…through coursework and/or research opportunities to contribute in their focus area professionally."[11] This example is not provided as either a positive or negative case—it simply illustrates the challenges that all biological engineering programs will face as they attempt to redefine themselves and emerge from an existing discipline in which they are firmly, and perhaps necessarily, rooted. The question, however, must be raised as to whether the specialty courses exist within the biological engineering program, or should students simply be directed to a different department to gain focus and specialization? A similar question arises as to the research opportunities for capstone design projects. At USU we have been bringing required courses into the Department (such as Thermodynamics and Modeling) in order to provide the necessary "bio" focus.
- *Absence of specialization*. Trying to work outside of the department's core expertise. Reductionism is generally the accepted approach for attaining a Ph.D. in science, technology, engineering, and mathematics. While extending one's specialized (Ph.D. level) knowledge to

a broader problem can provide new and nontraditional approaches, it is more likely to not lead to a successful result. The same applies at the departmental level. At USU the name change required bringing in new faculty with specialization in chemical engineering, bioengineering, Materials Science, and analytical chemistry to complement the old guard rooted in traditional Agriculture and Irrigation Engineering. The breadth of faculty knowledge extends beyond the walls of the classroom or teaching laboratory into faculty research laboratories for capstone design projects as well as post graduation connections with industry and graduate programs.

- *Loss of Autonomy*. Waiting for the community to define its standards before defining program curriculum dulls the edge and flexibility that attract students to a hybrid discipline. Standardized, seemingly inflexible programs unable to meet changing (local as well as global) interests and markets led to the name change in the first place.

Restructuring USU Biological Engineering Core Curriculum

The goal of curriculum design is to create a plan that will enable the faculty to implement its stated aims and goals. Not planning will lead to poor alignment in what Fenwick English describes as the real curriculum (what actually happens), the written curriculum (what is described, if in no other place than the course catalog), and the tested curriculum (what is evaluated)[12].

Profits (Curriculum Level)

- *Courses can be designed to be balanced and well-scoped*. In biological engineering, common principles apply to a variety of applications in different specialization areas (i.e. bioprocessing, biomedical, bioenvironmental). Ensuring that core courses offer a balanced set of examples, problems, labs, etc. representing the full breadth of applications is important to match diverse student interest and career paths. As an example in our bioinstrumentation course, we teach data acquisition appropriate for EKG measurements as well as soil moisture content. The fundamentals of data acquisition and signal processing form the core content, with specific applications gauged at student interest. In another case our biomaterials course originally had many laboratories that featured agricultural materials. As part of the restructuring materials of importance to biomedical and bioprocessing were added including use of contact lenses in moisture sorption studies and biopolymers in material property experiments.
- *Integration between courses can occur.* Moreover, continuity across the vertical axis of the curriculum (between courses offered across multiple years), and integration across the horizontal axis of the curriculum (between courses offered in the same year) are likely outcomes. Key topics, concepts, competencies, themes can be identified and tracked. Survey research of our own students and faculty reveal agreement on the point that our program lacks sufficient repetition of the content of some critical content areas. The core competency that students should be able to use simulation and modeling is an example of this at USU. Modeling theory and examples were added as part of the concepts taught in the introductory courses and an additional biological engineering modeling course was added to the curriculum as a technical elective. Modeling examples are being added to core courses including Unit Operations and Transport Phenomena.

- *Opportunity to use technology to a greater extent in curriculum mapping.* Curriculum mapping is commonly used in our primary and secondary educational systems but not as much in higher education. The purpose of curriculum mapping is to make the links between different elements of the curriculum explicit, e.g. between different types of content and competencies, learning outcomes, and assessment objectives. We believe that such a tool could prove to be a great benefit encouraging different programs to compare and evaluate their curricula with other programs.

Pitfalls (Curriculum Level)

- *Not discussing the philosophy of a program*. There does not need to be complete unanimity in a faculty regarding its philosophy and the aims, goals, and objectives of its curriculum, but if the subject never becomes a matter of discussion among the faculty and an explicit communication never reaches the students, they are likely to feel like they are "flying blind" through their education because they will not fully understand what they are expected to do. Consequently they will have a tendency to experience frustration.
- *If it ain't broke don't fix it*. Are students passing the FE exam? Are they receiving job and graduate school offers?
- *Overspecializing*. For example, focusing only on biomedical applications in the instruction. Biological engineering as a discipline has positioned itself as a science-based discipline.

Course Level Improvements

With a curriculum plan in place the focus naturally shifts to improving various courses in the program. On this level there are some interesting dynamics at work. For example, the process of course development can be very time consuming and given the high demand on faculty time, especially young new faculty, the task is often prohibitively time consuming. Our faculty report that they spend up to five times longer (sometimes 20 hours per week) in preparing for new classes. Even for a mature course, half of our professors feel like they spend too much time in preparation. The question becomes what to focus on and who should do it?

Profits (Course Level)

- *Maximizing instructional efficiency and effectiveness*. Students need a variety of learning experiences inside and outside of the classroom. Some of these should be very carefully designed, even to the extent of building intelligent tutoring systems based on cognitive task analyses. Others can be enhanced by simple learning objects[13].
- *Potential for collaborative development of course materials.* With the aid of exciting new technologies in the field of open content (e.g. Connexions at Rice University, and Open Courseware collections like those found at MIT and USU), the opportunity arises for individuals, both faculty and students, to use, modify and extend existing course materials. This is a relatively new development in the world of education and holds potential for vastly changing the landscape of educational material production. We view it as a possible way to fill the void created by a general lack of textbooks specific to the biological engineering domain.
- *Focusing more on what happens before and after class*. At USU we are employing online quizzing before and after class to require students to come to class more prepared, to free up

class time for more problem-based instructional activities, and to reinforce what students have learned in previous classes and labs. These should occur before, during, and after class.

Pitfalls (Course Level)

- All courses require constant revitalization, content updating, and review. The primary obstacles for course level changes are cost (laboratory development, T.A. support, instructional technology assistance) and associated effort—but considering the general status of engineering education[14] these impediments have to be circumnavigated to revitalize all of engineering, not just biological engineering.

Summary

The practicality of moving beyond the department name change to reformation of biological engineering at the discipline, curriculum, and course levels requires several key elements. From our experiences at USU, the following key changes have been instrumental to the success of our program beyond the name change:

- *Addition of new faculty*. Faculty are required having the breadth of specializations to meet the teaching and research needs. Since 1999 four new faculty with degrees in Chemical Engineering, Bioengineering, Materials Science, and Analytical Chemistry have been hired. Additional research diversity has been attained through adjunct appointments—but remember, you get what you pay for.
- *Administrative vision (new department head)*. The impact of new faculty additions will be diminished if they are restricted by lack of new vision and resources at higher levels. In our department, a changing of the administrative guards was filled internally, which had the added benefit of inserting a leader familiar with the resources, centers, and similarly aligned programs at USU. Equally important to our success has been the support at the state and national levels. The Utah Governor's Engineering Initiative Fund has allowed for the new faculty hires while providing resources for teaching laboratories and state of the art classrooms. National Science Foundation support has allowed us to enhance our courses with assistance from the Instructional Technology Department at USU. Delivery of core content through digital resources has allowed in-class time to focus on hands-on, experiential learning, giving a more personalized touch to the undergraduate program. NSF funding has also permitted curricular restructuring, providing opportunities to our students to more readily participate in off-campus internships during the academic year, offering greater flexibility to our industrial partners.
- *Industrial partners.* Establishment of a diverse industrial advisory board has provided critical feedback to our program while providing our students with greater internship and employment opportunities. A particularly important feature has been exit interviews conducted by the IAB, allowing the students to openly and objectively discuss their education with outside reviewers. The IAB provides a summary report to the department head and the curriculum chair as part of our ABET self-assessment process.
- *ABET 2000.* Through ABET we have gained a level of introspection into our program that would have otherwise been neglected due to sheer effort. The assessment procedures allow for rapid response to concerns at the curricular and course levels, feeding into the general

goal of redefining biological engineering to best meet our local needs as well as serve as a more global template for others.

- *Core philosophy definition.* Defining a core philosophy of learning by doing research has given our program a strong character. Improving the instructional quality of classroom materials can develop as time goes by, but our course offerings are being structured in such a way as to integrate research into our undergraduate experience right away, and build on that experience all the way through Junior and Senior Design. This way our students obtain career relevant learning experiences immediately and progress from the periphery to the core of authentic practice quite naturally[15]. We have also changed our course structure so that seniors can use their final semester for a cooperative experience or internship. Establishment of an undergraduate research culture in biological engineering is a significant investment of faculty time and resources, but the potential productivity of a student who has been personally trained over four years may provide a worthwhile return on investment to the faculty (especially in contrast to the generic first year graduate student who is burdened with courses, qualifying exams, and lack of experience). As for the undergraduate students, research forces them to come out into the open and get involved. In most cases this also promotes group work experience for our students. An additional benefit of this focus is that our undergraduates become our graduates. In a very real sense we are priming the pump for our graduate program. Finally, an interesting aspect of undergraduates engaging in research is that they are more open to work on projects that might be characterized as high risk – high return, where the prospect of "no return" does not mean failing to complete a graduate thesis on schedule.
- *Student empowerment.* The most critical change we have implemented has been to address each of our 85 students as an individual. At the class level this meant providing relevant examples to the students in Biomaterials, whose interest varied from biomedical to bioremediation to a single agriculturally inclined student. With this knowledge, the course instructor was able to extend the core concepts of this sophomore level course into individually relevant examples, term projects, and suggest research projects for capstone design early in the student's career.
- *Capstone design*. The importance of research has been implemented through the curriculum, starting with the first year. Reformatting of capstone design theses to model journal publications and funding of undergraduate student participation at conferences are the foundation of Biological Engineering at USU. Combined with the restructured curriculum favoring industrial internships, we feel that even in the absence of a strict definition of biological engineering at the discipline, curriculum, and course levels, our students (and their future employers) will associate this degree with versatility and practical training in research and publication.
- *Involve specialists and faculty dedicated to educational effectiveness.* Our summary conclusion is that the effort required to truly prepare students for engineering jobs of the future in the field of biological engineering, utilizing best practices and existing research, is to involve faculty and even specialists from colleges of education who have special expertise with learning and instructional design, and the variety of information technologies that are changing the educational landscape.

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