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Emergence of Biological Engineering at the University of Arkansas*

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This paper describes the changes that took place in 1984–2003 as the University of Arkansas developed an undergraduate program in biological engineering as a replacement for a traditional agricultural engineering program. In the early 1980s, the faculty recognized that engineers with biological tool sets could be utilized in a broader context (beyond traditional agricultural industries) with wider opportunities for employment. Program changes that were adopted to allow graduates to embrace these new opportunities included: (1) increased requirements for basic biological sciences, and (2) increased coverage of life support systems, growth kinetics and bio-processing. The accompanying changes in faculty expertise and student recruiting and enrolment are presented.

Keywords: agricultural engineering; biological engineering; curriculum reform; ABET

INTRODUCTION

MANY BIOLOGICAL ENGINEERING PROGRAMS have recently emerged, and several of these programs have been developed by departments formerly named 'Agricultural Engineering'. One such program has been developed by the Biological and Agricultural Engineering Department at the University of Arkansas (UA). The undergraduate program now embraces biomedical engineering as one of its areas of concentration, along with Ecological Engineering, and Biotechnology Engineering. This paper traces the recent history (1984–2003) of the changes that took place to move from a traditional agricultural engineering program to the present biological engineering program.

DESCRIPTION OF AGRICULTURAL ENGINEERING PROGRAM (*CA.* 1984)

Agricultural Engineering, as a profession in the US, developed to provide engineering services targeted to agricultural industries (both production and processing) and to the general rural clientele associated with agriculture [1]. Most agricultural engineering educational programs originated at Land Grant universities whose mission it has been to serve this clientele. The Agricultural Engineering Department at the UA was established in 1920 [2], and the undergraduate program was accredited in 1955 [3]. The department has administrative and working ties both to the College of Engineering and the College of Agricultural, Food and Life Sciences. Faculty typically have had 12 month appointments, with 20% teaching responsibilities, and an 80% time commitment to do research with the Arkansas Agricultural Experiment Station.

In 1984, the program produced graduates who were hired primarily in farm machinery design (tractors, tillage equipment, planters, harvesting equipment, etc.), design of grain handling/storage/drying facilities and equipment, and design of on-farm water control structures for irrigation and conservation of soil and water resources in agriculture. The BS AgE program consisted of a general engineering curriculum with upper level engineering courses geared toward providing the needed design skills of the targeted industry. The areas of concentration in the program were Electric Power in Agriculture, Crop and Food Processing, Soil and Water Engineering, Agricultural Structures, Agricultural Power and Machinery, and Agricultural Waste Engineering (UA Catalog [4]).

The four-year program included 132 semester hours divided among: two English composition courses (6 hours), four courses in calculus and differential equations (16 hours), a 5-hour chemistry course, 18 hours of humanities and social sciences, 8 hours of university physics, 9 hours of introductory engineering (design fundamentals, computers, graphics, circuits), 11 hours of agricultural/biological science (botany, soils, crops), 15 hours of core engineering sciences (statics, dynamics, thermodynamics, mechanics of materials, fluid dynamics), 29 hours in upper level core agricultural engineering subjects, 12 hours of technical electives and 3 hours of free electives. The upper level agricultural engineering core included: field machinery, agricultural engines and tractors, agricultural structures, properties of agricultural

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materials, agricultural instrumentation, agricultural-crop processing, agricultural equipment design, soil and water engineering.

Of the 132 hours in the curriculum, an estimated 15 hours involved inherently biological subject matter. Much of the engineering design, applied to systems that included agricultural crop-plants and livestock/poultry animals, was accomplished effectively with the organisms represented as black boxes (with known, stable properties). Notable exceptions included the physiologic modeling of heat production of confined animals and the soil–plant–water relationships used to analyze evapotranspiration and irrigation demand.

MOTIVATING CHANGE

Demand for agricultural engineering graduates decreased as the rapid adoption of new technology and mechanization in production agriculture (starting prior to World War II) began to stabilize in the early 1980s. Declining student enrollment (Fig. 1) was observed due, in part perhaps, by the demographics of declining numbers of farms and fewer high school graduates interested in pursuing careers related to production agriculture. The UA undergraduate program's existence was threatened by a low student enrollment during the period 1985–1991.

While agricultural production world-wide has continued to grow out of the necessity to feed an increasing world population, the most challenging engineering problems in agriculture today (especially in developed countries) involve either post-harvest technology and product development, or the management of finite soil/water/air resources between urban residents and agriculture, competition that threatens the sustainability of agriculture and the continued utilization of broad expanses of land for food production. The complexity of most contemporary agricultural engineering challenges requires the ability to account for organisms at multiple trophic levels—communities, individuals, organs, tissues, cells, molecules. There was a growing need to integrate an understanding of biology with a competency to apply that knowledge to solving problems.

As faculty attempted to prepare students in Arkansas to meet these challenges, we realized that the enhanced biological skill set that was needed could be utilized in a broader context (beyond traditional agricultural industries) with more opportunities for employment and greater potential benefit to the public we serve. Hence, program changes were adopted to allow graduates to embrace these new opportunities. Moreover, a new biological emphasis, it was thought, might appeal to a broader range of potential student interests, and lead to increased student enrollment. So, a curriculum that was specialized toward meeting the needs of a mature industry was developed

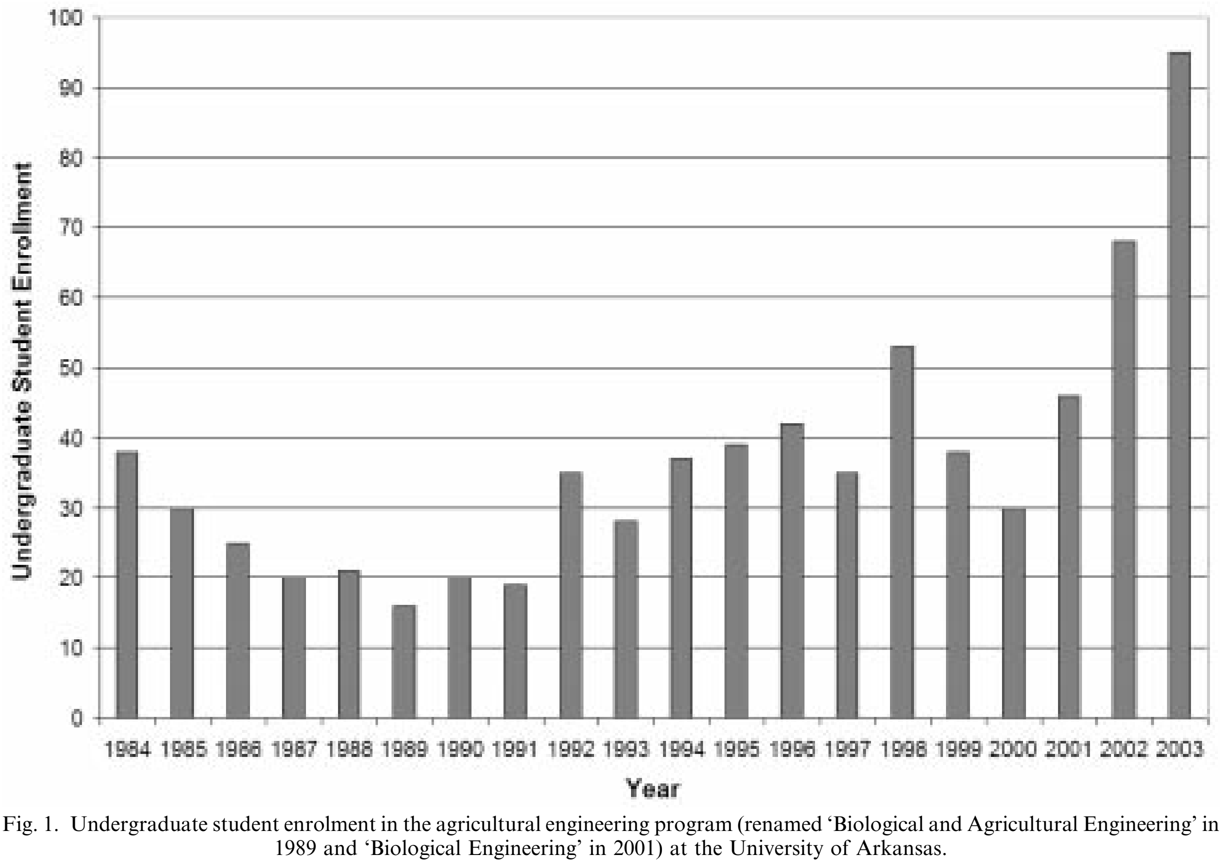

Fig. 1. Undergraduate student enrolment in the agricultural engineering program (renamed 'Biological and Agricultural Engineering' in 1989 and 'Biological Engineering' in 2001) at the University of Arkansas.

further to provide a science-based biological tool set to a new generation of engineers.

HISTORY OF CHANGE

Program change (1988)

In the mid-late 1980s, the growth of computer-based technologies was exploding as a means to help farmers improve profitability by identifying/eliminating unnecessary costs of production and by increasing yield through detailed, timely management recommendations [1]. It became evident, that in order to capitalize on this technology, agricultural engineers needed a better quantitative understanding of biology. Following the trend, in which agricultural engineering researchers were building ties across engineering, mathematics, computers and biology, in 1988, the undergraduate program was changed to add two courses in Biosystems Engineering. These courses provided students with skills in mathematical modeling of plant and animal systems, with applications to design in mostly agricultural settings. The new material provided a method to estimate life support requirements for animals and plants based on an understanding of basic physiological processes. The courses added quantitative biology to the engineering toolbox.

The 1988 program change, in addition to the introduction of biosystems courses, altered the mix of biological/agricultural sciences that were required. The requirement of botany, soils and crops was replaced with a continued requirement of soils (which we considered a basic biological science for agricultural engineers) plus an 8-hour block for biological sciences electives, allowing students to explore general biology, microbiology, zoology, etc. The program change also reduced emphasis on farm machinery design (eliminated the course in field machinery) and introduced a two-semester senior design sequence. The change in program content is summarized in Fig. 2.

Along with this curriculum change, the department name and degree name were changed to Biological and Agricultural Engineering in 1989–1990. The name change reflected the faculty and administration's recognition of the trend toward increasing prominence of basic biological knowledge in the practice of traditional agricultural engineering, as well as recognition that our graduates were capable of making significant engineering contributions outside of strict agricultural enterprise. This is reflected in the addition of Premed (preparation for medical school) as a degree program concentration in 1990.

Program change (1996)

Faculty decided to strengthen the lower level engineering exposure in 1996 by introducing a two-semester freshman sequence and by moving one of the biosystems courses to the sophomore year.

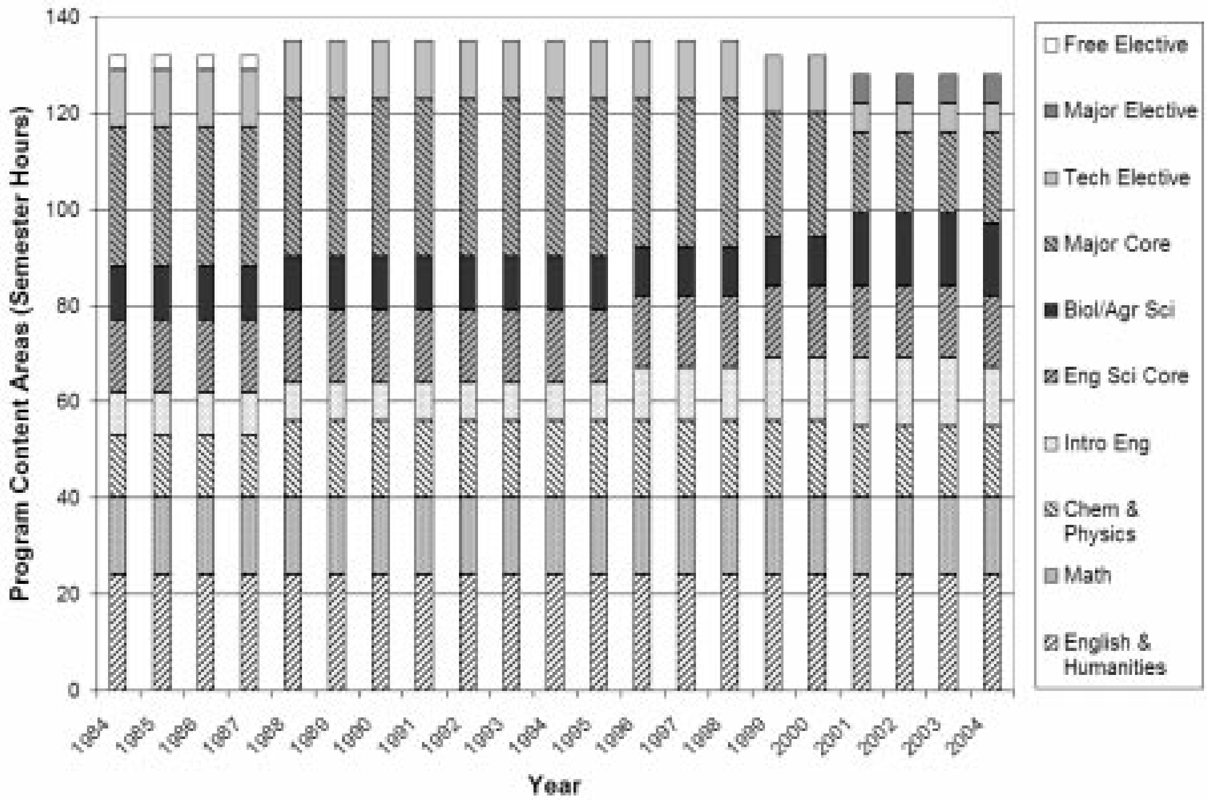

Fig. 2. Division of program content by topic area. Data shown for the agricultural engineering program (renamed 'Biological and Agricultural Engineering' in 1989 and 'Biological Engineering' in 2001) at the University of Arkansas.

These three courses, along with the sophomore electric circuits class, provided continuous course-contact between the department and the students for the entire freshman and sophomore years. This was intended to improve retention and help younger students to obtain a better grasp of the engineering design concepts that they are expected to apply as upper level students. The 1996 change also included a split of the 5-hour Soil and Water Engineering course to two, 3-hour courses (Water Resources Engineering and Bio-Environmental Engineering). Students had complained that a 5-hour class was onerous and we wanted to strengthen the environmental emphasis (since this area had remained a steady source of employment through the years). The areas of concentration for students at that time were: Bio-Environmental Resource Engineering, Food and Process Engineering, Pre-medical, Structures and Environment, and Power and Machinery. Most of the student interest and jobs were concentrated in the first two areas; whereas, the last two areas were holdovers that corresponded to research areas of current faculty at the time (see Fig. 3).

Program change (1999)

The degree requirements were reduced from 135 to 132 hours in 1999 by reducing three courses by one hour. This streamlining was facilitated by moving the second biosystems course from upper level to the sophomore year and creating a two-semester sophomore sequence in biophysical systems (later renamed Quantitative Biological Engineering in 2001). The sophomore sequence was intended as a scaffolding course, exposing inexperienced students to hands-on, real-world engineering problems that are tackled by designing a process or a device, based upon analysis which revolved around an understanding of the biological components. This new sophomore sequence not only improved the abilities of the students to attack problems that were inherently biological, it also provided skills in hardware and fabrication that their peers in other programs lacked. The scaffolding concept also was intended to increase the students' intuitive understanding of engineering subjects, thus building a base from which they might better absorb the engineering science core—courses that many students seemed to endure without retaining the competency that upper level engineering instructors expected.

The Department underwent a period of administrative uncertainty during the period from 1997 to 2001, with leadership provided by two successive interim heads. Faculty numbers declined as the Dean of the College of Agriculture (who had budgetary authority over the department) searched to define/refine the mission of the department. During this time, student enrolment began to

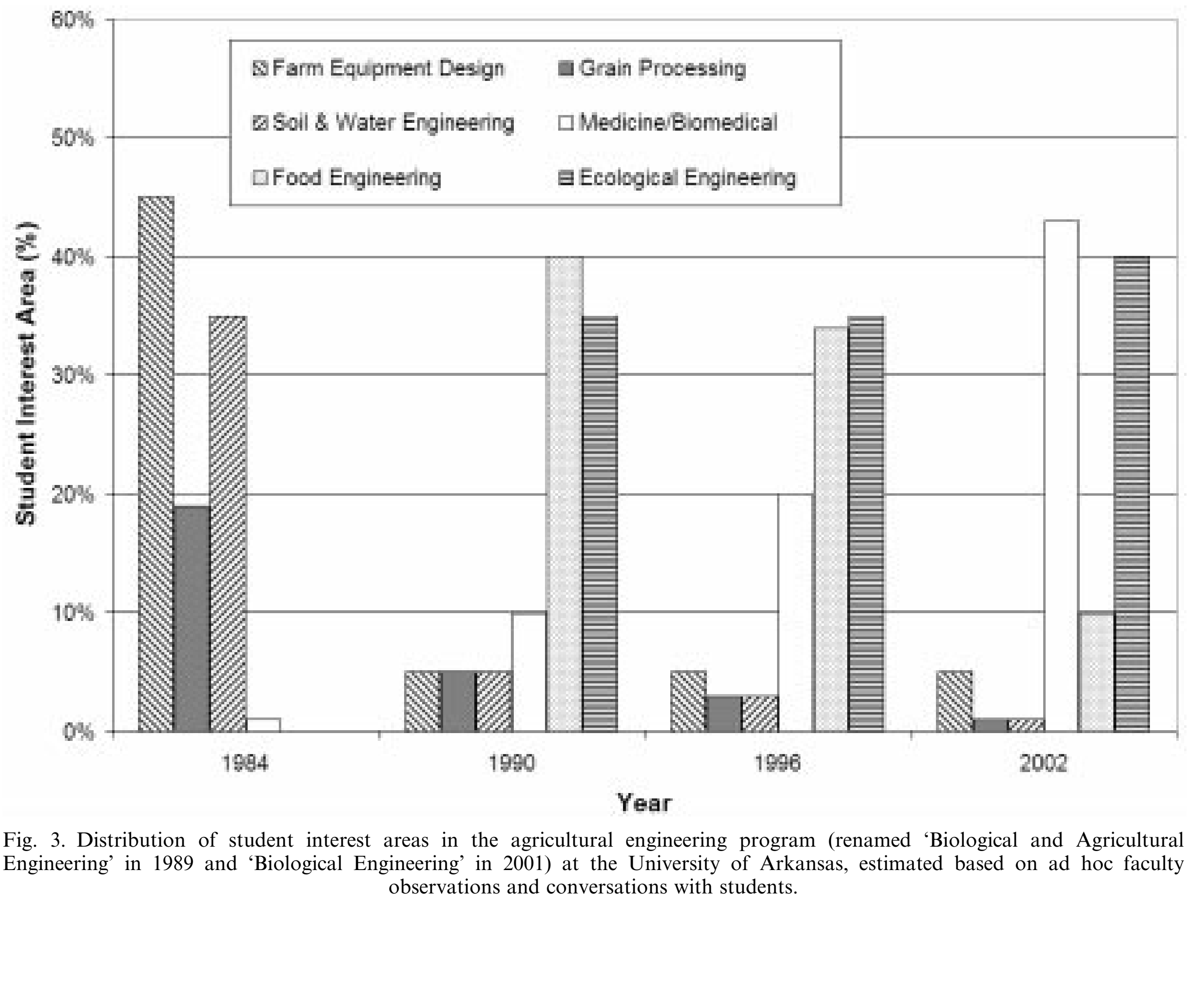

Fig. 3. Distribution of student interest areas in the agricultural engineering program (renamed 'Biological and Agricultural Engineering' in 1989 and 'Biological Engineering' in 2001) at the University of Arkansas, estimated based on ad hoc faculty observations and conversations with students.

decline due to rumors about the long-term viability of the program. By 2000, only two full-professors remained, and the young faculty, as a whole, were ready to complete the transition of the program to Biological Engineering.

Program change (2001)

After UA administration made the decision to re-invest in the program, a permanent head was hired in 2001, and the faculty (existing plus newly hired, Fig. 6) proceeded to change the degree name to Biological Engineering and developed the required program changes (Fig. 2), including: requiring an expanded biological sciences core of all students (consisting of fundamental biology, microbiology, organic chemistry and biochemistry), moving the required upper level design courses in the major to a list of design electives (of which two were to be selected depending upon the individual student's interest area), adding a two-semester bio-process engineering sequence (which stressed kinetics and bio-conversion processes) at the junior level (originally 4 hours but increased to 6 hours in 2004). The faculty designed an integrated curriculum that involved biological content in all courses, with coverage extending to four areas of concentration: Food and Bio-Process Engineering, Ecological Engineering (formerly Bio-Environmental Engineering), Bio-Resources Engineering (formerly Biomechanical Engineering) and Biomedical Engineering. The 2001 program change embraced engineering applications in the area of human health (these had been previously avoided).

DISCUSSION OF CHANGE

The change in the name of the degree to Biological Engineering in 2001 reflected a real change in the curriculum, relative to the program in 1984. The required courses in the major were each selected and designed to incorporate knowledge of basic biology into engineering practice. This systematic design of the integrated curriculum was part of our on-going program quality improvement process, as required by our accreditation agency (see [5]). Students were required to take 15 hours of basic biological sciences starting in 2001 (Fig. 2), compared with 10–11 hours required prior to the change (with the majority of the courses in the older program strictly focused on agricultural sciences). The fraction of the curriculum that dealt with biological content increased from an estimated 15% in 1984 to 48% in 2004 (Fig. 4). The remaining content was necessary educational components common with other engineering disciplines (i.e., English, math, chemistry, physics, humanities, etc.).

The biological/biomedical emphasis embraced in

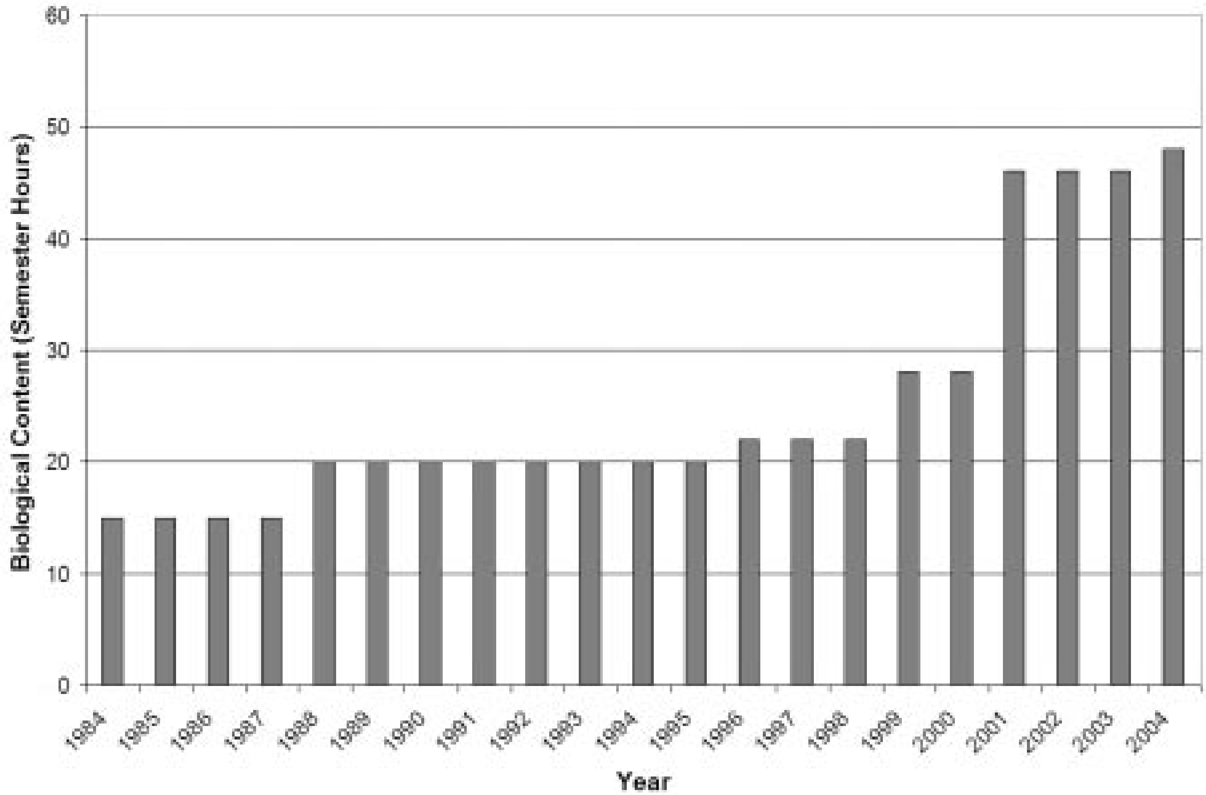

Fig. 4. Content of program (number of semester hours) that was inherently biological. Data shown for the agricultural engineering program (renamed 'Biological and Agricultural Engineering' in 1989 and 'Biological Engineering' in 2001) at the University of Arkansas.

2001 was accomplished by hiring faculty who were educated in biological sciences, biological engineering and biomedical engineering (Fig. 5) to complement existing faculty who were mostly the products of traditional agricultural and chemical engineering programs. Faculty continued to focus the majority of their research effort in agricultural application areas (Fig. 6), because research funding for most positions in the department continued to come from the Agricultural Experiment Station. Funding for biomedical engineering faculty has come through the College of Engineering. By 2001, some faculty were actively seeking and conducting research in applications that were not explicitly agricultural.

Student interests—estimated by faculty through interviews with students—changed over the 20 year period (Fig. 3). By 1990, incoming students no longer came primarily from farm settings and had a diminished interest in traditional agricultural engineering specialty areas, including farm machinery, grain processing, and soil and water. Note that the environmental component of the program (soil and water engineering subsequently transitioned into 'Ecological Engineering') continued to be a stable interest area over the entire period. Although grain processing interest declined, a spike in interest in food engineering in the 1990s corresponded to significant faculty involvement in food safety research along with a demand for graduates to work in the poultry processing industry. With the addition of a biomedical engineering concentration area in 2001, the majority of incoming students began to express interest in this non-agricultural application area. Faculty have observed that many entering freshman who are initially designated as 'premed' eventually adopt one of the other biological engineering areas prior to graduation.

Owing to shifting student interests and program changes, our recruiting efforts also changed. In the late 1970s, recruiting consisted of visiting high school agriculture classes, county fairs and science fairs—meeting potential students and making contacts with vocational agriculture teachers and county extension agents. The incoming students resulting from these contacts came primarily from farm settings; unfortunately, students that came from an urban background were missed through this recruiting strategy. Also, students, with an interest in biology and mathematics, which were normally courted by Arts and Science colleges, would not be contacted through these recruiting practices. By the mid-1980s, faculty effort in making personal contacts at high schools had diminished because these recruiting practices were no longer successful, as shown by the declining student enrolment numbers presented in Fig. 1.

Around 1990, recruiting relied on mass mailing of brochures and videos to high school counselors

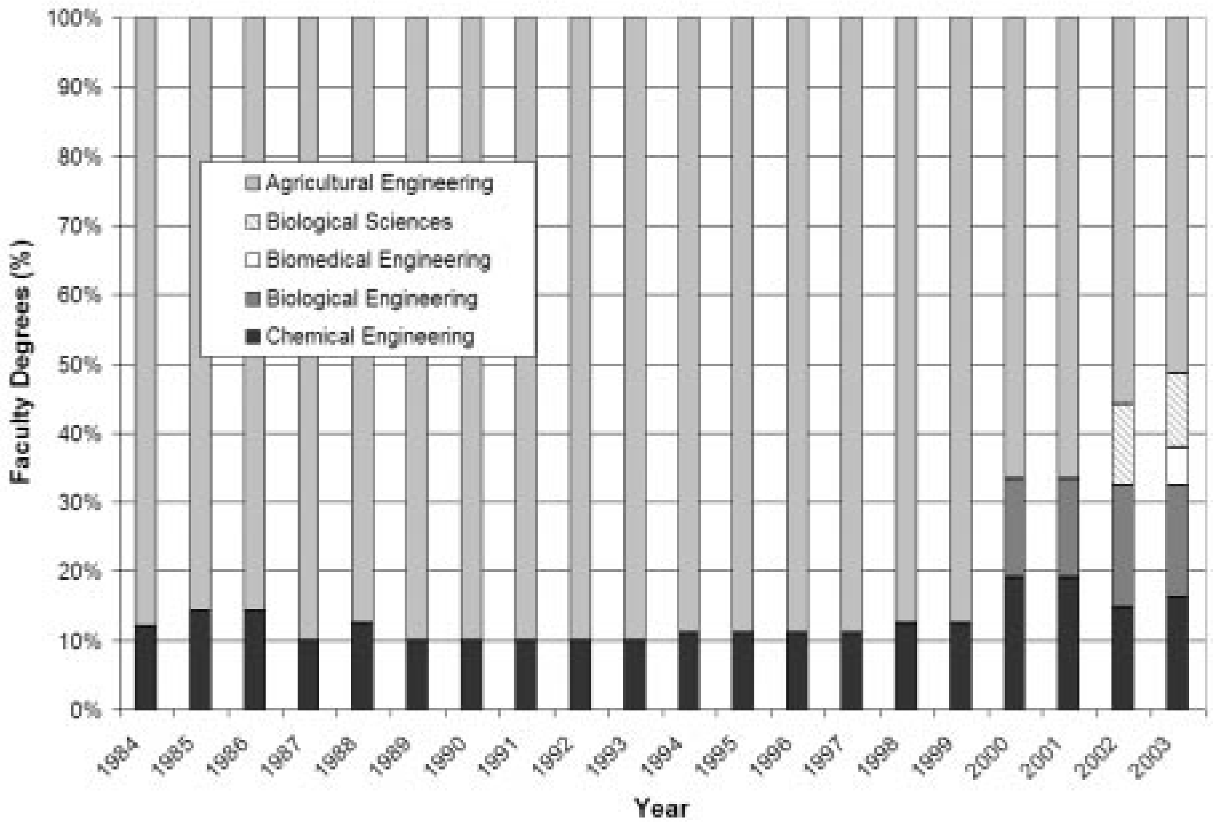

Fig. 5. Distribution of discipline areas where faculty were educated and earned college degrees. Includes BS, MS and Ph.D. degrees. Data shown for the agricultural engineering program (renamed 'Biological and Agricultural Engineering' in 1989 and 'Biological Engineering' in 2001) at the University of Arkansas.

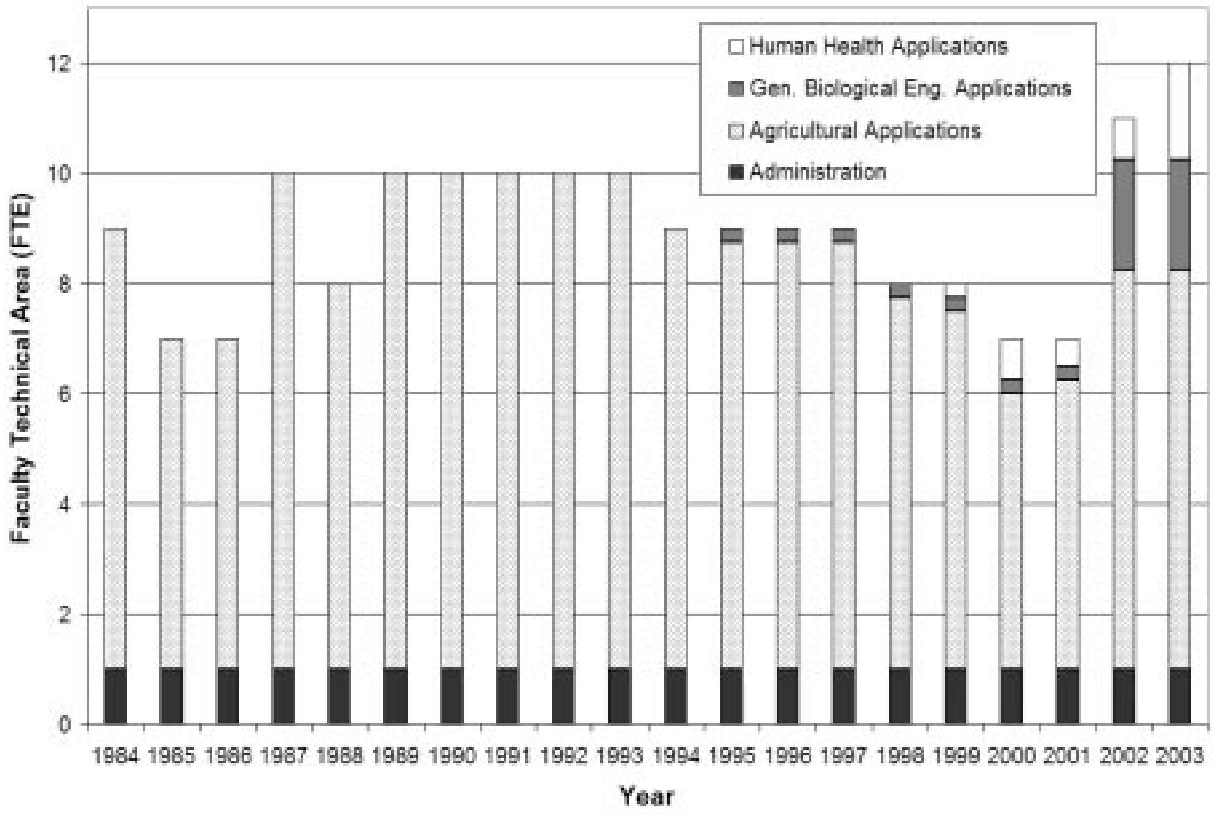

Fig. 6. Distribution of faculty technical areas (research specialties), expressed in full-time equivalents (FTE). The FTE allocated to the teaching program was approximately one-fifth of the total, since most faculty had only a 20% teaching appointment. Data shown for the agricultural engineering program (renamed 'Biological and Agricultural Engineering' in 1989 and 'Biological Engineering' in 2001) at the University of Arkansas.

and math/biology teachers. Alumni of the program were also encouraged to help with recruiting by making high school visits. These efforts, along with the change in degree name to Biological and Agricultural Engineering, helped to create an increase in enrolments in the period from 1992 to 1998.

In the summer of 2002, Biological Engineering began to work with Industrial Engineering, who already had in place a vigorous recruiting strategy. A key element in this recruiting program was that the recruiters consisted of discipline specific junior and senior students—rather than faculty. Approximately fifty high schools were visited each Fall, specifically targeting chemistry, biology or physics junior classes. The student recruiter gave a 20 minute presentation on both programs and on available scholarships, leaving ample time for questions. All the juniors that attended these presentations filled in a response card with their name, home addresses and contact phone numbers. Students who expressed interest in Biological Engineering were contacted by phone by a recruiter and were invited to a campus tour. It is important to note that the tour was given by the same recruiter who had made the telephone contact, establishing a more personable contact. During the tour, the prospective student and the accompanying parent(s) would meet with a faculty member. With this recruiting strategy, prospective students with urban backgrounds or with an interest in biology and engineering were contacted. This recruiting effort, along with the appeal of the biological/biomedical program (rather than agricultural engineering) may have helped increase student enrolments dramatically in 2001–2003 (Fig. 1).

With the decline of students entering with a farm background, faculty noticed that students were coming with less hands-on experience. A strength of agricultural engineering programs had been the perception that graduates not only were well-educated across a broad engineering base, but were also capable of attacking problems with an intuitive feel for what was feasible and an ability to follow a project through design, fabrication, testing and implementation. This was an attribute that we wanted to maintain among biological engineering graduates. To do that, we involved freshmen and sophomores in team design projects that not only take them from analysis and paper design, but allow them to see their creations come to fruition by fabrication and testing. This experience, including observation of failure of their designs, has been valuable to students in their development as engineers who understand how biological systems work, and know how to use engineering tools to solve problems with a biological component. Our student teams are frequent winners of national design competitions.

With increased enrollment, especially in new areas such as biomedical engineering, there is strong need to follow up the curriculum changes with a vigorous attempt to partner with industry/clientele who could benefit from the hiring of our graduates. Our students need to be linked up with internship opportunities (as suggested by [6]) and job interviews. Potential employers need to know what our graduates can offer. And, the program faculty need to be made more aware of the types of problems biological engineers tackle in the workplace, so that faculty can select realistic homework assignments and projects that will increase the value of our graduates' professional contributions. This is one challenge that needs to be completed.

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REFERENCES

1. O. J. Loewer, Biological engineering history, in *Encyclopedia of Agricultural, Food and Biological Engineering* (Dennis Heldman, ed.), Marcel Dekker, New York, NY, (2003).
2. G. Zellar and N. Wyatt, *History of the Bumpers College: Evolution of Education in the Agricultural, Food and Life Sciences in Arkansas*, Arkansas Agricultural Experiment Station Special Report No. 194, Arkansas Agricultural Experiment Station, University of Arkansas, Fayetteville, AR, (1999).
3. Billy B. Bryan, Personal communication with former department head of the Agricultural Engineering Department, University of Arkansas, Fayetteville, AR, (2004).
4. University of Arkansas, *Undergraduate Studies Catalog*, University of Arkansas, Fayetteville, AR, (1984–2004).
5. T. A. Costello, C. L. Griffis and L. Verma, A computer-based interactive package for ABET self-study, *Proceedings of the 2002 American Society of Engineering Education Annual Conference and Exposition*, Montréal, Québec, June 16–19, 2002 (2002).
6. A. T. Johnson and W. M. Phillips, Philosophical foundations of biological engineering, *J. of Engr. Educ.,* **84**(4), 1995, pp. 311–318.

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