

ENHANCING BIOENGINEERING OPPORTUNITIES FOR ENGINEERING MAJORS

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Abstract – In response to evolving expectations for its engineering graduates, Michigan State University is developing a plan to enhance undergraduate student learning in the field of bioengineering. Although this paper focuses on enhancing bioengineering opportunities for engineering majors, several lessons have been learned that might be applied as other institutions develop strategies to systematically reform their undergraduate engineering programs. For example, the following factors have been identified that impact the sustainability of curricular-change initiatives: the role of strategic planning within the academic unit and at the institutional level; the leadership role of department chairs/heads and college deans; the role of faculty planning, faculty assessment, faculty development and faculty autonomy; the system of values and rewards for individual faculty and for their academic units; and the role of constituent groups in establishing and evaluating educational program objectives and curricular outcomes.

Index Terms – Bioengineering, Biomedical engineering, Collective responsibility, Educational reform, Planning and outcomes assessment.

INTRODUCTION

Michigan State University (MSU) is in the process of developing a plan to enhance undergraduate student learning in the field of bioengineering. An interdisciplinary team composed of faculty from the College of Engineering and the College of Education has undertaken this project. Bioengineering was selected as the focus for this reform effort because the State of Michigan recently announced a \$1B commitment to developing *A Michigan Life Sciences Corridor*. This commitment was made recognizing the need and timely opportunity for Michigan:

- to diversify its economy through the creation of jobs in areas related to the life sciences and
- to improve the quality of life and improve the health care of its citizens.

This commitment focuses on the development of a basic and applied research infrastructure to support the long-term achievement of this goal. A properly educated and trained engineering workforce will help realize this, and engineers will play an important role in transforming scientific

breakthroughs into useful products because of their technical expertise in areas such as materials, instrumentation, control, electronics, mechanics and manufacturing. This plan to reform undergraduate education—and to enhance undergraduate student learning in the field of bioengineering—addresses the following factors that affect the sustainability of curricular-change initiatives:

- the role of strategic planning within the academic unit and at the institutional level;
- the leadership role of department chairs/heads and college deans;
- the role of faculty planning, faculty assessment, faculty development and faculty autonomy;
- the system of values and rewards for individual faculty and for their academic units; and
- the role of constituent groups in establishing and evaluating educational program objectives and curricular outcomes.

Traditionally, members of a department faculty value their autonomy. However, their home department has a set of *collective responsibilities* involving other departments in the college, the university, and external constituent groups. Consider the following scenario. Faculty members in a particular department are judged individually to be very well qualified. Each person's academic and other scholarly achievements can clearly be documented as meritorious. However, the sum of individual activities and achievements may fall measurably short of their department's collective responsibilities. More specifically, an individual might bring highly innovative concepts into an existing engineering course that are highly valued by external funding agencies, by peer institutions, and by the employers of the department's graduates. More importantly, these innovations may not be compatible with the department's curricular thrusts and are lost once this person is no longer the course instructor. Hence, while an individual member of the faculty—or a small subset of the faculty—might champion a very worthwhile curricular change, these changes will most likely not be sustained unless the academic unit makes these changes part of the overall faculty's collective responsibility, rather than merely the responsibility of the faculty change champions. This theme—the tensions between collective responsibility and faculty autonomy—resonates throughout this paper.

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This paper provides the background for and challenges associated with developing a plan to enhance bioengineering opportunities for engineering majors at Michigan State University. The first section of this paper presents some baseline information needed to understand the rationale for enhancing bioengineering opportunities for engineering majors at MSU. This section is followed by a review of higher-education literature related to systemic curricular reform. Within this context, we then present the opportunities and challenges facing the reform efforts and the lessons learned to date. The relationships among faculty autonomy, the collective responsibility of the department faculty, and systemic reform in undergraduate engineering education are examined. It also places these concepts in the narrow perspective by examining ways to enhance bioengineering opportunities for engineering majors and the broader perspective of engineering curricular reform in general. The paper concludes by identifying a specific set of outcome measures to assess the success of curriculum changes that will lead to enhancing bioengineering opportunities for engineering majors at MSU.

BASELINE FOR CURRICULAR REFORM EFFORTS AT MICHIGAN STATE UNIVERSITY

Curriculum reform requires the existence of a compelling rationale for changing educational objectives or outcomes. As part of the information needed to clearly articulate this rationale, baseline information about the existing undergraduate programs administered through the College of Engineering at Michigan State University [1, 2] was developed. The content of the various academic programs and—in particular—the opportunities for engineering majors to take concentrated coursework in bioengineering as part of their normal degree requirements has been examined. Understanding this baseline data also enabled the development of a set of metrics that would be applied to assess the success of the actual reform efforts. Some key information resulting from this baseline study is summarized in the remainder of this section.

Undergraduate Engineering Programs—An Overview

The College of Engineering at Michigan State University has six departments—Agricultural Engineering, Chemical Engineering and Materials Science, Civil and Environmental Engineering, Computer Science and Engineering, Electrical and Computer Engineering, Mechanical Engineering—and 141 tenure-stream engineering faculty members. Each year, approximately 3500 students are enrolled in the College of Engineering academic programs, 625 graduate with B.S. degrees, and 225 graduate with M.S. (180) or Ph.D. (45) degrees. Students are sought by over 300 corporations and attend over 40 different graduate schools.

The College administers nine undergraduate degree programs, seven of which are ABET accredited. The degree programs are as follows: Biosystems Engineering (BE),

Chemical Engineering (ChE), Civil Engineering (CE), Computer Engineering (CpE), Computer Science (CpS), Electrical Engineering (EE), Engineering Arts (EA), Materials Science and Engineering (MSE), and Mechanical Engineering (ME).

While the university requires a minimum of 120 credits for graduation, only two of these programs—Engineering Arts and Computer Science—require this minimum. Each of the other seven programs requires 128 credits. Within this total, students must also fulfill “University Requirements” (24 credits), “College Requirements” (30 credits), and “Program Requirements” (variable credits). Elective courses then complete the student’s academic program.

We have examined the course requirements for each of the nine majors and can draw the following three general conclusions.

- Student programs are generally quite rigid, especially the programs that are ABET accredited. For example, if electrical engineering students elect to include a Biomedical Engineering Option in their academic programs, then the number of credits needed for graduation would most likely exceed 145 credits—17 more than the 128 credits needed to obtain to complete the B.S. requirements for electrical engineering.
- Greater flexibility in the selection of courses needed to complete the “University Requirements” and “College Requirements” would enable students to plan amongst a more diverse set of areas of concentration within their degree program. This is because students tend to fulfill these requirements during their freshman and sophomore years, without giving adequate thought to how these courses will fit into their overall educational objectives and experiences.
- The existence of interdisciplinary courses such as bioengineering within an academic department depends strongly upon the interests of individual faculty members in the department. Hence, the existence of interdisciplinary-type program options also appear to be directly related to the interest of individual faculty members rather than upon a broader vision and set of educational objectives and outcomes. Consequently, student achievement is not generally equated to the successful completion of a concentration of study, such as biomedical engineering—but rather in the context of technical achievements within the narrowly defined engineering discipline itself.

These three observations suggest that several important barriers exist that tend to impede curricular reform—i.e., a very rigid set of course requirements within the major, the lack of flexibility in fulfilling university-level and college-level requirements, and faculty autonomy as they define educational objectives and outcomes for the courses they teach and the curricula they oversee.

Bioengineering Opportunities for Current Students

Although these barriers exist, a core group of engineering faculty has been actively involved—individually and in small groups—to champion bioengineering opportunities for undergraduate engineering majors at MSU. For example, consider biomedical engineering (BME) teaching and research. In the late 1970s and throughout the 1980s, seven engineering faculty from four engineering departments offered eight BME courses as part of a formal BME Option (minor) program. These members of the faculty functioned in their teaching and research activities as BME faculty without formal administrative recognition. Their dedication to BME was evident by one or more of the following characteristics: they had earned a Ph.D. working on BME topics, worked as biomedical engineers in industry, sustained records of external support for BME research, or had a continuous record of graduating M.S. and Ph.D. students who completed BME research theses.

Students from traditional majors obtained a BME Option by selecting five BME technical electives and five life science courses. Students then graduated from their traditional department with the additional BME Option certification. Throughout the 1980s, typical BME class sizes were 25-30 students, with similar numbers graduating each year. These students found jobs in BME industries such as orthopedics, medical devices and the FDA. The Dean's office, rather than a specific academic department, administered the BME Option; however, different departments controlled BME teaching assignments. BME courses were then often assigned to a faculty member in addition to their normal teaching responsibilities. The typical BME faculty had three graduate students; however, the graduate program has yet to receive degree status.

Unfavorable university-wide fiscal conditions during the 1990s, coupled with the lack of a fixed administrative unit, were concomitant in reducing the number of undergraduate BME courses in half. The reduction in course offerings created a BME Option, which requires three BME courses and two life science courses and led to a decrease in the number of BME undergraduates to 15-20 per year. Although the *absolute* number of undergraduates graduating with the BME option has decreased, the *ratio* of the number of these students to the number of faculty teaching BME courses has remained constant. The enthusiasm for the educational activities, however, has only increased.

In spite of the lack of historical BME data at MSU, the current number of students per BME faculty is comparable to the averages cited for the 10 largest ABET-accredited programs. Here, the average number of B.S. in BME per year per faculty is 4.8 and the average number of graduate students per BME faculty is 4.5. Traditional BME research strengths at MSU have been in the areas of biomechanics, biomaterials, biochemical processing, and cryobiology.

There are many opportunities for synergism between BME and the biological sciences. MSU is one of the few

campuses in the nation with three medical schools. The College of Human Medicine (CHM) is a national leader in educating primary care physicians. In addition to its educational excellence, the College of Osteopathic Medicine (COM) has nurtured biomechanics expertise. The College of Veterinary Medicine (CVM), ranked among the top three in the nation and a founder of the American College of Veterinary Surgeons, is a national leader in orthopedics and biomechanics developed in collaboration with engineering faculty.

In addition to engineers working on challenges in the medical field, MSU is also home to cutting-edge plant-based pharmaceutical research. Indeed, the future of plant and microbial-based biotechnology is extremely bright as evidenced by the \$20M in research funding over the past five years awarded in the College of Engineering. A research proposal has recently been submitted to apply MSU biotechnology expertise presently used for large-scale production of microbes or plant cells to the large-scale production of mammalian cells for tissue engineering applications.

The current presence of bioengineering at MSU extends beyond the BME Option; however, it is distributed—and somewhat fragmented—in four of the different academic programs administered within the College of Engineering [1, 2]. For example, a concentrated set of courses in biochemical engineering can be taken as an elective area of concentration within Chemical Engineering; biomaterials engineering within Materials Science and Engineering and biomechanics within Mechanical Engineering. Additional areas of concentration are being discussed. These include Biothermal engineering in Mechanical Engineering, and Biosensing and Bioimaging in Electrical Engineering.

There are 21 tenure system faculty who have self-identified themselves as having their primary research interest as bioengineering. Six of these were hired in the last three years in the Department of Electrical and Computer Engineering, in part, to develop research in bioimaging. Many of the engineering faculty interested in BME-related research recently joined together to develop and formalize a new interdisciplinary BME graduate program that is in the process of being reviewed by various academic-governance bodies. It is hoped that this effort at the graduate level will eventually lead to enhancing opportunities for bioengineering at the undergraduate level.

SYSTEMIC CURRICULAR REFORM

This section provides important background information on past and present curriculum reform efforts in higher education, with an emphasis on engineering education. Understanding what others have learned about curriculum reform has helped us by providing a context for guiding our efforts to enhance bioengineering opportunities at MSU. Lessons learned by others have helped us better understand

the inherent challenges of curriculum reform and has aided us in developing strategies to deal with these challenges.

Historical Perspective on Curriculum Reform In Undergraduate Education

The unresolved tensions within undergraduate education in the United States since the mid-18th century have been well-documented [3]. These tensions focus around the goals of undergraduate education, the content of the curriculum, instructional strategies, curricular evaluation, and the assessment of student learning [4]. These tensions will undoubtedly remain part of the debate about what undergraduate students should know and who will make those decisions. The classical (general) education curriculum stood essentially unchanged from the early 17th century until science courses were added during the mid-1700s in response to the desire for more scientific inquiry. Academic specialties and the department system were added in the early part of the 19th century to accommodate the expanding curriculum and desire for distinct disciplinary identification [5]. Since then, the pace of curriculum reform has increased. A broad range of courses was added to an increasingly more unstructured curriculum between 1945 and 1975 [3].

Debate about the undergraduate curriculum gained center stage in the public arena from the mid-1980s to the mid-1990s with the release of several critical reports and reform proposals. Some of the authors of the critical reports [6-8] argued that general education had become incoherent and ineffective and failed to adequately equip graduates with the intellectual tools needed for life in a democratic society. Various individuals and groups proposed specific remedies for reform as a means of rectifying the “crisis” in undergraduate education [9-11].

Current Curriculum Reform In Undergraduate Education

Curricular issues in the early 21st century continue to move gradually from the exclusive domain of the faculty and institutions of higher education to the public arena where many external stakeholders are involved in the reform process. Some of the external forces that help sustain the momentum in curriculum reform include shrinking public support, declining state funding, uncertain and shifting federal research funding, demands for accountability from the public and accrediting bodies, technological advances, privatization, shifts in employment opportunities for graduates, and shifts in public policy [12, 13]. Internal pressures for curriculum reform are largely the result of the desire for new degree programs, student demand, intra-university competition for resources, competition for new faculty, budget constraints [14] and new—and often rapidly changing—leadership [15].

Seventy-five percent of all colleges and universities, including MSU, were involved in curricular reform in the late 1980s [16]. Reforming undergraduate education at MSU

is a continuous “work-in-progress” which builds on the framework established in the university’s *CRUE Report* (Committee to Review Undergraduate Education) in the mid-1980s and the more recent 1999 *MSU Promise & Guiding Principles* [17]. In addition, during 1995 and 1996, MSU participated in the ACE Project on Leadership and Institutional Transformation to enhance the intensity of the academic environment [16] in support of the efforts to continually reform MSU’s undergraduate education.

Curriculum Reform in Undergraduate Engineering

Curriculum reform in undergraduate engineering is, in large measure, driven by external stakeholders [18-19] that challenge engineering educators to partner with the broader educational community, state and federal government bodies, and the private sector to revitalize engineering education in ways that would ensure that technical graduates were better-prepared for work in a complex economic, political, and international environment. In addition to changes in curricular content, one of the foci of curriculum reform in undergraduate engineering education has been on teaching strategies. There is evidence that some approaches to teaching and learning facilitate better student learning. Cooperative learning, collaborative learning, peer learning, problem based learning, and experiential learning are examples of teaching and learning that are effective in undergraduate education [20]. These methods are important because of the uneven preparation by students [21] and differences in their learning styles [22-23]. These methods can also be employed as strategies to help students achieve the complex skills and abilities mandated in the outcomes—ask in Criterion 3 of the engineering criteria of the Accreditation Board for Engineering and Technology (ABET). The types of knowledge needed to achieve these skills and abilities require that students to have the opportunity to acquire information as well as develop skills, exercise judgment, and apply wisdom through practical application [24].

Systemic reform in higher education requires a comprehensive conceptual model which includes the external environment, the institution and college, the department, faculty work, and student learning [25]. While the curriculum and design of the courses requires significant expenditures of time and resources, the process of reform is equally as intense [26, 27]. The change process is long-term, evolutionary, and requires effective leadership [16] that understands the academic values and unique culture of higher education, its system of shared governance, reward structures, tenure, and goal ambiguity [16, 28]. It is essential to establish trust among the curriculum’s constituents to facilitate effective collaboration [27, 29] and to help internal and external stakeholders make sense of the change [28]. Furthermore, In order to be successful in this educational reform effort, the traditions of disciplinary boundaries, structural issues, autonomy, fear of change, and the

perception of resource barriers (people, faculty, facilities, money, leadership) must be reduced.

DISCUSSION

Michigan State University received a grant from NSF [31] to develop a plan to systemically reform its undergraduate engineering educational programs and to enhance undergraduate student learning in the field of bioengineering. This project was undertaken by an interdisciplinary team composed of faculty from the College of Engineering and the College of Education.

We define *systemic reform in education* as the process of periodically and systematically reviewing and modifying the productivity standards and productivity criteria of an academic unit, coupled with the concomitant modifications in structures and policies within the unit that are needed to effect the desired changes in educational outcomes. Ideally, this is a continuous process and an integral part of the culture of the academic unit, as well as the institution itself.

Bioengineering was selected as the focus for this reform effort because the State of Michigan had recently announced a \$1B—i.e., \$50M/year, twenty-year—commitment to developing *A Michigan Life Sciences Corridor*. This commitment was made recognizing the need and timely opportunity for Michigan:

- to diversify its economy through creation of jobs in areas related to the life sciences; and
- to improve the quality of life and improve the health care of its citizens.

Although this state commitment focuses on the development of a basic and applied research infrastructure, we assert that a properly educated and trained engineering workforce will help realize this goal by transforming scientific breakthroughs into useful products.

Approach

Our approach focuses on the following inter-related tasks:

- Identify external constituents that would benefit from the reform efforts and document their support for the proposed reform efforts. Leverage this support as one of the compelling arguments for reform.
- Benchmark key peer institutions to understand what has already been done with respect to bioengineering education. Identify key programs and institutions that have made successful strides in reforming their undergraduate engineering programs or have developed distinctive bioengineering areas of concentration.
- Review the higher-education literature to better understand curricular reform issues and to help gain insights into successful strategies for achieving reform.
- Develop baseline data regarding current bioengineering opportunities in the various academic programs and develop strategies for expanding these opportunities.

- Develop reform strategies and share these with others both internal and external to the institution. The pros and cons of different aspects of the strategies need to be delineated and openly discussed.

This approach serves several important purposes. First, it helps develop the set of compelling arguments that will be required to move forward with the reform efforts. Second, it helps inform key administrators and key faculty members that will ultimately need to become champions of the reform effort. Finally, it helps achieve faculty commitment.

Principal Findings

After examining the graduation requirements for each of the nine undergraduate academic programs administered through the College of Engineering at MSU, we have been able to draw the following conclusions:

- Limited bioengineering opportunities exist within the College of Engineering; however, they are generally very distributed and fragmented. Moreover, they not well advertised/marketed by the College of Engineering.
- Specific programs of study are quite rigid. Hence, if students elect an interdisciplinary set of courses in a bioengineering concentration, they will most likely have to take an additional semester of course work beyond that required for their engineering degree.
- Enhancing student learning in bioengineering will require close cooperation among department faculty and chairs in establishing learning outcomes, developing innovative instructional approaches, developing faculty incentives and designing structures and policies to encourage their use.

Reform Strategies and Measures of Success

After reviewing the higher-education literature and placing lessons learned in the context of MSU, we have formulated the following strategies as we proceed with reform efforts:

- *Develop a set of compelling arguments* for enhancing bioengineering opportunities for students.
- *Share these arguments* with the dean, chairs, and key faculty; seek ways to have them become champions of the reform effort to obtain faculty commitment.
- *Assist the dean, department chairs, and key faculty* in developing and publishing a reform plan, including timelines and quantitative measures of success.

The college and its academic departments formulate annual plans and occasionally update their strategic plans. Moreover, MSU will be preparing its self-study reports for ABET in preparation for its next general review during the 2004-2005 accreditation cycle. One important measure of this project's success will be to assess what these planning and self-study reports specifically propose to accomplish with respect to reforming the engineering curriculum. For example, will the next set of ABET self-study reports

identify bioengineering at one of the foci for undergraduate education at MSU? And will these reports identify specific program outcomes that support these enhanced bioengineering opportunities for students?

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REFERENCES

- [1] *Engineering Undergraduate Studies*: Michigan State University College of Engineering, URL: <http://www.egr.msu.edu/egr/programs/bachelors>, March, 2003.
- [2] *Academic Programs 2002-2004*: Michigan State University College of Engineering, URL: <http://www.msu.edu/unit/ucandc/updated/index.html>, March, 2003.
- [3] Cohen, A., *The Shaping of American Higher Education: Emergence and Growth of the Contemporary System*. San Francisco: Jossey-Bass, 1998.
- [4] Stark, J. S. and Lattuca, L. R., *Shaping the College Curriculum: Academic Plans in Action*. Boston: Allyn and Bacon, 1997.
- [5] Rudolph, F., *The American University: A History*. New York: Alfred A. Knopf, 1962.
- [6] Bennett, W. J., *To Reclaim a Legacy: A Report on the Humanities in Higher Education*. Washington, D. C.: National Endowment for the Humanities, 1984.
- [7] Wingspread Group On Higher Education, "An American Imperative: Higher Expectations for Higher Education," The Johnson Foundation, Racine, Wisconsin, 1993.
- [8] Association of American Colleges, *Integrity in the college curriculum: A report to the academic community*. Washington, DC: Association of American Colleges, 1985.
- [9] Association of American Colleges Task Group on General Education, "A new vitality in general education," Association of American Colleges, Washington, DC, 1988.
- [10] Boyer, E. L., *The undergraduate experience in America*. New York: Harper and Row, 1987.
- [11] Association of American Colleges, "Sustaining vitality in general education," Association of American Colleges, Washington, DC, 1994.
- [12] Altbach, P. G., Berdahl, R. O., and Gumpert, P. J., *American Higher Education in the Twenty-first Century*. Baltimore: Johns Hopkins University Press, 1999.
- [13] Leslie, D. W. and Fretwell, E. K. J., *Wise Moves in Hard Times: Creating and Managing Resilient Colleges and Universities*. San Francisco: Jossey-Bass, 1996.
- [14] Morphew, C. C., "Understanding the acquisition of new degree programs," presented at the 22nd Annual Meeting of the Association for the Study of Higher Education, Albuquerque, NM, ERIC Document Delivery Service No. ED 415 801, 1997.
- [15] Birnbaum, R., *How Colleges Work: The Cybernetics of Academic Organization and Leadership*. San Francisco: Jossey-Bass, 1991.
- [16] American Council on Education, "Riding the waves of change: Insights for transforming institutions," American Council on Education, Washington, DC, 2001.
- [17] McPherson, P., "The MSU Promise and the Guiding Principles." East Lansing, MI: Michigan State University, 1999.
- [18] American Society for Engineering Education, "Engineering education for a changing world," American Society for Engineering Education, Washington, DC, ERIC Document Delivery No. ED 382 447, October 1994.
- [19] Engineering Education Commission, "Criteria for accrediting programs in engineering in the United States: Effective for evaluations during the 1998-99 accreditation cycle," Accreditation Board for Engineering and Technology, Baltimore, MD, 1999.
- [20] McKeachie, W. J., *McKeachie's Teaching Tips: Strategies, Research, and Theory for College and University Teachers*. Boston: Houghton Mifflin, 2002.
- [21] Fisher, P. D., "Lessons learned: The process for achieving systemic reform," 2000.
- [22] Entwistle, N. and Tait, H., "Approaches to studying and perceptions of the learning environment across disciplines," in *Disciplinary differences in teaching and learning: Implications for practice*, N. Hativa and M. Marincovich, Eds. San Francisco: Jossey-Bass, 1995, pp. 93-112.
- [23] Fisher, P. D., Fairweather, J. S., and Amey, M., "Systemic reform in undergraduate engineering education: The role of collective responsibility," presented at 31st ASEE/IEEE Frontiers in Education Conference, Reno, NV, 2001.
- [24] Gorman, M. E., "Turning students into professionals: Types of knowledge and ABET engineering criteria," *Journal of Engineering Education*, vol. 91, no. 3, 2002, pp. 327-332.
- [25] Middleton, N. T. and Trefny, J. U., "Managing human processes in curriculum reform," presented at the Frontiers in Education Conference, 1998.
- [26] Merton, P., Clark, C., Richardson, J., and Froyd, J., "Engineering curricular change across the foundation coalition: Potential lesson from qualitative research," presented at the 31st ASEE/IEEE Frontiers in Education Conference, 2001.
- [27] Kezar, A. and Eckel, P., "Balancing the core strategies of institutional transformation: Toward a "mobile" model of change," presented at the American Educational Research Association, Montreal, Quebec, Canada, 1999.
- [28] Weick, K. E., *Sensemaking in Organizations*. Thousand Oaks, CA: Sage Publications, 1995.
- [29] Fisher, P. D., "Assessment process at a large institution," presented at Proceedings of the 1998 ASEE Annual Meeting and Exposition, Seattle, WA, 1998.
- [30] Fisher, P. D., Fairweather, J. S., and Haston, L. A., "Establishing learning objectives and assessing outcomes in engineering service courses," presented at the 30th ASEE/IEEE Frontiers in Education Conference, Kansas City, MO, 2000.
- [31] National Science Foundation, "Enhancing bioengineering opportunities for engineering majors," Award #0230058, National Science Foundation, 2002.