AC 2011-715: INTEGRATING BIOLOGY AND ENGINEERING

Cindy Waters, North Carolina A&T State University (Eng)
Sanjiv Sarin, North Carolina A&T State University (Eng)

Sanjiv Sarin is a Professor of Industrial Engineering and Associate Dean of the College of Engineering at North Carolina A&T State University. He received a Bachelors degree in Chemical Engineering from the Indian Institute of Technology, New Delhi and a Ph.D. in Industrial Engineering from the State University of New York at Buffalo. He is a member of ASEE and IIE, and a registered Professional Engineer in North Carolina.

Integrating Biology and Engineering

Abstract:

This paper presents planned activities and some recent successes related to collaborative efforts between engineering and biology at North Carolina A&T State University. For many years, faculty in engineering and biology have teamed up to submit research proposals, much of this collaboration has occurred through personal relationships among faculty members. More recently, the university has encouraged a formal and intentional cooperation between the two disciplines in an effort to find mutual benefits. Spurred by the establishment of new bioengineering degree programs and helped by the NSF Engineering Research Center for metallic biomaterials, the partnership between engineering and biology has strengthened and is yielding significant benefits for students. The partnership has grown in several dimensions including coursework, funded proposals, joint faculty positions, and shared facilities. During 2010 a team of faculty representing engineering and biology and administrators were awarded an NSF Innovation through Institutional Integration (I^3) grant titled EBEE: Enhancing Bioscience and Engineering Education through curriculum integration and research experiences in systems biology. The main theme of the project is to incorporate life sciences education and research across the campus and to demonstrate it by creating intentional and sustained collaborations between the College of Engineering and the Biology Department at North Carolina A&T State University (NCA&T).

One example of cross-campus sustainable collaborations is team teaching by faculty from the two disciplines. The mechanical engineering department faculty has recognized that research into new biomaterials is a significant area of emphasis for modern materials research and therefore is an area worthy of study. In order to prepare students, the regularly scheduled course entitled Modern Engineering Materials is being upgraded to include biomaterials. Recognizing that the human body is an amazing machine made up of a series of macro and nano-scale systems including biological pumps, valves, pipes, filters, wiring, as well as contents under pressure, the course will be team taught by engineering and biology professors. In order to introduce undergraduate engineers to these connections, a module was created to identify and study relationships between structure and function in human body tissues and to investigate medical device design. In turn, engineering faculty will help the biologists in helping them use systems biology to model the same physiological systems. Systems biology is a comprehensive quantitative analysis of the manner in which all the components of a biological system interact functionally over time. Engineering faculty will in turn assist the biology faculty in incorporating systems biology into their curriculum.

University Background

NCA&T, a Historically Black College/University (HBCU) and land-grant university, is one of four Ph.D. granting institutions within the NCLSAMP Alliance, and the largest producer of minority engineering graduates in the country. During 2008-09, NCA&TNCA&T had the highest percentage (44%) increase of graduate school applications among doctoral degree granting institutions in the University of North Carolina (UNC) system. Moreover, 150 master's degrees and 14 doctoral degrees were awarded in fall 2008, an increase of 6.5%. In spring 2009, 209 master's degrees and 19 doctoral degrees were conferred. Over 90 percent of full-time tenure track faculty members at NCA&T have doctorates, and for the fifth consecutive year, NCA&T is ranked third in the UNC System in terms of sponsored funding totaling $57.7 million in 2009. NCA&T currently offers 89 bachelors, 43 masters, and 6 doctoral degree programs. NCA&T is committed to broadening the participation of underrepresented minorities in STEM programs. Several new initiatives are being planned in this regard, including the appropriation of university funds to broaden student participation in STEM, the establishment of a university wide STEM committee, and the creation of an undergraduate research office.

The University's new Chancellor announced his goal of positioning the university as a leader in STEM education. In honor of this commitment, in the 2009-10 academic year he has appropriated $250,000 towards financial support for STEM graduate students. Furthermore, he has made a commitment to increase funding up to $1 million for the 2010-2011 academic year. The university also receives a special allocation of state funds for tuition remission for STEM students who are US citizens or permanent residents. Several other efforts have begun which are new to our campus.

To harness university wide support for STEM related activities, the Chancellor has appointed a Committee on STEM Initiatives that is charged with exploring how STEM-related departments and programs can work collaboratively to advance this vision. The committee is chaired by the Dean of the College of Engineering at NCA&T. In addition, NCA&T recently established the Office of Undergraduate (OUR) Research which will centralize undergraduate research efforts on campus. This office will have a website that gives students a single place to find what undergraduate research opportunities are available, on- and off-campus. It will give faculty a place to advertise the opportunities that they have available. The Office's staff will assist faculty by offering training in best practices in mentoring. They will also work with faculty and students to find the best match for each mentor-mentee relationship. The staff will help students find opportunities to present their research on-campus and at regional and national meetings.

The overarching theme of the recently awarded NSF Innovation through Institutional Integration (I^3) project (EBEE Enhancing Bioscience and Engineering Education) is to integrate life sciences education and research across the campus and to demonstrate it by creating intentional and sustained collaborations between the College of Engineering and the Biology Department at NCA&T. The EBEE program will capitalize on the growing interest in systems biology and the natural synergy between engineering and biology to achieve the ideals of systems biology. In support of this synergy, a university-wide interdisciplinary cluster of faculty, staff and students is being established by the Provost to broaden collaboration among bioscience and engineering disciplines. The cluster includes members of the project team and representatives from the wider university community with specific interests and background in the life sciences, systems biology, computational methods and engineering. This cluster will meet periodically to develop strategies for future directions of the project, and to explore additional avenues for enhancing collaborative work among faculty and students from different disciplines.

Why the integration of engineering and biology

The life sciences have become increasingly quantitative as new technologies facilitate collection and analysis of vast amounts of data ranging from complete genomic sequences of organisms to satellite imagery of forest landscapes on continental scales. There is a need for rapid diffusion of new mathematical, computational, and engineering methods in the life sciences. As a consequence, mathematics and computational science have become crucial technologies for the study of complex models of biological processes. Bioengineering and systems biology partnerships are key for better understanding of living systems. This is done through reverse engineering in mathematical analysis, numerical simulation, data collection, refinement and improvement of models based on comparison with experimental data. However, realistic models of biological networks are not simple, and scaling to deal with large biochemical networks remains a major challenge. On the other hand, engineering researchers are quite familiar with robust control theory, dynamical systems, and related areas. Input from such engineering principles is key is for biologists apply these techniques to biological applications where there are multiple feedback signals, nonlinear component dynamics, numerous uncertain parameters, and stochastic noise.

An investment in systems biology approaches provides academic researchers a cross-disciplinary bridge for catalyzing mathematical research relevant to the life sciences at NCA&T. Mathematicians, life scientists, computational biologists, bioengineers can all benefit from using systems biology approaches to complex problems. Consequently, multiple science departments at NCA&T have recently have acquired significant cutting-edge laboratory resources. New synergistic research partnerships are emerging across traditional departmental infrastructures. Because the science department's past work has actively promoted, presented, and published genuine undergraduate cross discipline-related research, the departments have gained significant favor across the university[1]. We have strong administrative leadership support for rigorous undergraduate research activities. We gained buy-in from stakeholders by: (1) working from the ground-up with administration to promote campus-wide bioengineering research and training; (2) fostering associations between research and regular undergraduate academic courses; (3) creating and disseminating bioengineering teaching and learning modules and (4) enhancing learning community support at the interface of engineering and biology.

In order to be competitive for future careers at the intersection of mathematics, engineering and biology, our students must make explicit connections between these disciplines[2,3]. This is occurring on our campus through integration of genuine research and classroom experiences for undergraduates early in their academic career. Current work is focused on linking NCA&T the content for sequences of science and mathematics courses. Similar to traditional academic institutions, our science majors receive too infrequent scholastic focus on critical thinking, problem-based active learning, and undergraduate research experiences. Most of our undergraduate science courses at NCA&T remain essentially disciplinary in nature and in compartmentalized frameworks. This promotes a disjunction between biology and quantitative approaches[4]. All of this gives students a mistaken impression that engineering has limited application to biology, and too many of our students emerge from courses without a coherent picture of the critical links between different science areas (particularly engineering and biology). Most students and some of our faculty still have not embraced the integration of mathematics and biology in undergraduate education. Such faculty were typically educated at a time when biology in undergraduate education was descriptive, and they are still not comfortable increasing the quantitative rigor of their courses. By leveraging our recent surge of competitive research activity, innovative instruction, and collaboration, we are advancing our transformation to the next level by establishing a yet broader bridge for our undergraduates at the interface of engineering and biology. We have taken a proactive, intensive approach in order to bridge campus chasms by positively influencing academic programs through interdisciplinary training and strong evaluation and assessments. Our work will have significant spillover effects for our university by developing new interdisciplinary collaborations that benefit our students.

Other institutions recognize the need for these interdisciplinary collaborations. As an example Case Western Reserve University published in the fall of 2010 and article titled "From Biology to Mathematical Models and Back: Teaching Modeling to Biology Students, and Biology to Math and Engineering Students" in the Journal of Life Sciences Education published by the American Society for Cell Biology[5]. In this article they describe the development of a course to teach modeling and mathematical analysis skills to students of biology and to teach biology to students with strong backgrounds in mathematics, physics, or engineering[5]. Case Western's efforts follow very closely the plans NCA&T has for course development. Future work at NCA&T will also follow the guidelines set forth in the recent MIT report on Convergence of the Life Sciences, Physical Sciences and Engineering[6].

As an example, we may employ graphical systems-biology tools that use mathematical engines to enable biologists and engineers, collaboratively, to simulate, model, and analyze biochemical pathways in an integrated environment. Using a common interface and software improves communication among engineers and biologists and eliminates the need for specific tools at each phase of systems biology. For instance, biochemical pathway analysis studies organisms as systems comprised of elements that interact with one another through chemical reactions. Because of the complexity associated with examining pathways, computational systems biologists require model-based tools to graphically depict the pathways and a mathematical engine to accurately analyze experiment and simulation data. Using software compatible with systems biology markup language (SBML) teams of biologists and engineers import and export models specified using– an information standard for cooperative sharing, evaluating, and developing systems biology models.

<u>The State of Current Efforts:</u>

Faculty in engineering and sciences have had a long history of collaborating with each other on interdisciplinary research projects. This collaboration has helped the University in attracting some very significant funded projects from NSF and other funding agencies. However, this has not resulted in integration across the curricula and there are limited opportunities for students to take courses that integrate multiple disciplines or to consider double majors or different but related majors as they move from undergraduate to graduate studies. Some recent steps taken by the college of engineering and the department of biology as well as encouragement and support from the university administration will be promising.

We recognize two trends that have prompted us to find ways to explore strategies to formally coordinate biosciences and engineering education. One, the role of biosciences in engineering profession is now being identified as the new frontier with the recognition that advances in health care will occur only with new engineered tools for diagnosis and treatment. Second, the bioscience community has increasingly realized that fundamental advances in understanding biological phenomena will require advanced skills with engineering and computational tools. As a University, we are at the nexus of these trends and this provides us an opportunity to significantly change the way we educate the next generation of engineers and biologists. We are attempting to capitalize on this opportunity to realize a model of university-level integration of the most research-intensive departments on the campus. Specifically, the chemical, electrical, mechanical, and industrial engineering; bioengineering; computer science; computational science and engineering; and biology programs will participate in building, implementing and sharing this new model. In a subsequent phase, we will expand this model to other programs that have a natural interest in life sciences including programs in chemistry, animal sciences, nursing and natural resources.

This initiative is bolstered by the NSF I^3 grant that will integrate several STEM academic programs in the College of Engineering and College of Arts and Sciences and multiple ongoing NSF and non-NSF funded research projects while capitalizing on recent University level initiatives that complement the goals of the project. Currently funded projects that will participate in the I^3 project include the following..

- NSF North Carolina Louis Stokes Alliance for Minority Participation (NC-LSAMP)
- NSF Historically Black Colleges and Universities Undergraduate Program (HBCU-UP)
- NSF Engineering Research Center (ERC) on Revolutionizing Metallic Biomaterials, NSF EEC 0812348;
- NSF Science and Technology Center (STC) for the Study of Evolution in Action (BEACON)
- NSF Broadening Participation (BPC) Alliance for the Advancement of African-American Researchers in Computing (A4RC)
- NIH Minority Access to Research Careers (NIH-MARC)
- NIH Research Initiative for Scientific Enhancement (NIH-RISE)
- NSF S-STEM projects in industrial engineering and computer science

At this point we are early in the process but several events have occurred. There has been a set of joint workshops to teach MATLAB to biologists but these workshops were also attended by engineering faculty and students. While biology students and faculty learned the modeling capabilities of MATLAB, engineering students and faculty were exposed to the SIMBIOLOGY toolbox..

Recognizing that research into new biomaterials is a significant area of emphasis for modern materials research and therefore is an area worthy of study, the mechanical engineering department faculty has upgraded the course entitled Modern Engineering Materials to include a more extensive series of lectures on biomaterials. To kick off the unit a biology professor was invited to give the biologists perspective on the human body as a machine to the mechanical engineering students. The students are able to recognize that the human body is an amazing machine made up of a series of macro and nano-scale systems including biological pumps, valves, pipes, filters, wiring, as well as contents under pressure. Each month of the course the students worked to create a portfolio of articles concerning innovative material and advances in material science. During one month the student's topic was biomaterials. The portfolios included six articles of the individual students choosing, an executive summary and a brief class sharing reflection of the most interesting article. Anecdotal feedback from the students was quite exciting. As another exercise in the course a biomedical device manufacturers was contacted and a supply of their newly developed Bone cement was donated to the class. This material offered another opportunity to study the function, shape and material of human bone and test how this material forms a suitable substitute. Plans for the current semester include a bone testing lab. Portions of the exercise are shown below. The technical objectives will be to

1. Discuss the variety of material property choices that nature has made in various human body components.
2. Compare and contrast nature as a designer to human engineers as designers.
3. Explain the difference between *strength* and *stiffness* of a material.
4. Define the *ultimate tensile strength* and *modulus of elasticity* of a material.
5. Determine the modulus of elasticity of a bone using a bone bending apparatus.
6. Determine the ultimate tensile strength of a bone using a bone breaking apparatus.

The class will also discuss differences between nature as a designer and humans as designers.

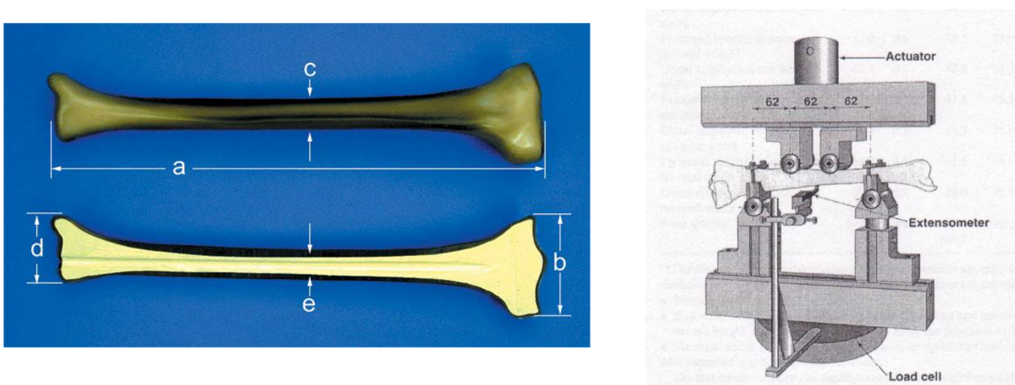

Figure 1. Bone test samples gage length determination and testing apparatus.

Future work:

Meaningful collaborations between engineering and biology faculty are beginning to occur and are likely to continue to strengthen. Currently, engineering faculty are helping the biologists in using systems approaches to model certain biological phenomena. . Also, biology faculty are team teaching to add depth and variety to the Modern Engineering Materials course. The Bioengineering program in the College of Engineering has dedicated a new faculty position that will be jointly appointed with the Biology Department. The Computational Science and Engineering program is also planning to assign one of its faculty positions as a joint position with Biology.

Through the I^3 project funds, we propose to introduce a novel approach to building bridges among the variety of ongoing funded projects. These bridges will promote greater awareness of a broader spectrum of research among undergraduate students and deeper understanding of cross-disciplinary research among faculty and graduate students. Fifty undergraduate students in engineering and biology will receive stipends to participate in systems biology based research and will be co-advised by two faculty members from different.

In the spring semester, the College of Engineering will collaborate with the Biology Department in its Annual Life and Physical Sciences Research Symposium which it has hosted for twelve years by introducing a new session on Systems Biology where the student researchers will present their work. The purpose of the symposium is to provide a forum for presenting recent developments in research, to inspire a new generation to seek scientific research careers and to inform the community about issues of health disparities

As regards curriculum development, we plan to create opportunities for undergraduate students in various engineering disciplines and in biology to enter into and succeed in the masters program in bioengineering. To facilitate this, a new accelerated BS-MS program will be developed for students in chemical, electrical, mechanical, biological, and industrial engineering and in biology. Students with high academic credentials in their freshman year will be admitted to the accelerated program that will allow them to receive a BS in their chosen discipline plus a MS in bioengineering within five years. Engineering programs will consider either adding biology courses as required or elective courses or replacing the current sequence of physics and chemistry courses with biology and/or biochemistry courses. Similarly, the biology program will consider adding engineering, computer science and computational modeling and visualization courses as required or elective courses for biology majors. Finally, faculty members in engineering and biology will collaborate in developing integrated courses in systems biology that would satisfy both engineering and biology curricular requirements. These strategies will promote engineering to biology students and biology to engineering students.

Acknowledgements: NSF EEC # 0812348: NSF Engineering Research Center for Revolutionizing Metallic Biomaterials

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