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Integrating Modern Biology into the ChE DNA through a Campus-Wide Core Laboratory Education Program

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INTRODUCTION

Efforts to infuse modern life sciences concepts into the traditional Chemical Engineering curriculum have accelerated in recent years, giving rise to a "new" sub-discipline, often referred to as *biomolecular engineering*. Chemical Engineering programs worldwide have embraced *biomolecular engineering* to the point that many departmental names now include this (or a related) moniker, reflecting a commitment to a permanent evolution of the discipline in this direction. One might argue that we have been here before (i.e., biochemical engineering), but the professional and technological driving forces to embrace biology within engineering have never been stronger. Our students are very interested in how biology fits into the Chemical Engineering discipline and how they can be prepared for professional opportunities in the biotechnology arena. As such, the task before us is to train students to function at the interface between Chemical Engineering and modern biology so that they can contribute in emerging areas ranging from biopharmaceuticals to biomaterials to bioenergy.

Truth be told, emphasis on the molecular life sciences (and other molecular sciences as well) has revitalized Chemical Engineering and will ultimately reinvent the discipline in many ways. However, with all this excitement comes a significant challenge – how to modify Chemical Engineering education so that its critical underpinnings are not slighted while, at the same time, going beyond a superficial treatment of the molecular life sciences. *In other words, Can a ChE "educational genotype" be developed that intrinsically and seamlessly integrates the life sciences?* This experiment is being currently being run at many institutions worldwide and requires rethinking of how Chemical Engineers are trained. To this end, many creative modifications of the undergraduate curriculum have been proposed and implemented to include biology. However, a major shortcoming typically arises: given the strong emphasis on sophisticated laboratory skills associated with the molecular biosciences and the lack of suitable lab courses and facilities on most campuses to deliver such training, how can an effective laboratory component be included? This is actually an issue not only for Chemical Engineering departments, but also for life sciences disciplines that need to provide laboratory-based training in modern biology for their students.

CORE LABORATORY TRAINING IN MOLECULAR BIOTECHNOLOGY

The expensive and sophisticated nature of laboratory techniques used in molecular biotechnology presents a challenge to those charged with developing pertinent instructional programs. In most cases, training along these lines on university and college campuses happens in a highly decentralized way: college-by-college, department-by-department or, for graduate students, research lab-by-research lab. These approaches seem to work at some level, but they suffer from several potential problems:

- The required effort and expense to carry out such training for particular programs can be prohibitive and, in the end, the results may be ineffective.
- In research labs, student-to-student "instruction" can propagate incorrect methodologies in addition to the fact that equipment, materials and supplies intended for research can be wasted as a consequence of the "learning curve".
- In isolated settings, interdisciplinary communication about new developments and advances in biotechnology techniques may not happen. Given the expanding array of disciplines, including biomolecular engineering, that can benefit from molecular biotechnology skills, decentralized training efforts will fail to capture this potential.

In any case, more effective strategies are needed to offset inadequate training in the range of lab skills associated with molecular biotechnology.

At North Carolina State University (NCSU), a core laboratory facility has been established and operates through its Biotechnology (BIT) Program (www.ncsu.edu/biotechnology) to teach molecular biotechnology skills to students campus-wide. This core facility was originally made possible by a unique funding arrangement between the colleges whose students benefited from the courses offered. Staffing was funded through a codicil between five colleges: Agriculture and Life Sciences, Engineering, Veterinary Medicine, Natural Resources, and Physical and Mathematical Sciences. The laboratory instrumentation and expendable supplies are covered through an allocation from a campus-wide educational technology fee, which allows the core facility to provide instruction in a modern laboratory setting with provision for continuous updating of instrumentation. *The overarching philosophy of the NCSU BIT Program is that molecular biotechnology encompasses a spectrum of theoretical knowledge, skills and lab techniques needed for advances in modern life science research and technology.* Molecular biotechnology is not an end in itself but rather a means to solve problems, unravel mechanisms and develop new technologies with societal benefit. The NCSU BIT Program is committed to enriching the base of scientific knowledge and laboratory skills necessary for genetic manipulation of living things at the molecular level. It also requires students to address the ethical issues surrounding biotechnology so that they can decide for themselves whether the merits of these new capabilities outweigh the associated risks.

CAMPUS-WIDE PARTICIPATION IN THE NCSU BIT PROGRAM

The NCSU BIT Program currently trains approximately 300 graduate and undergraduate students (as well as some postdocs, technicians, and faculty) annually, coming from over 35 Departments and Programs campus-wide. The BIT courses are very popular, and most sections fill each semester. From Fall 2001 through Spring 2008, there have been over 2,300 enrollments in BIT courses, representing students in 8 out of 10 of the colleges at NCSU. Non-matriculated students may take courses through Lifelong Education (LLE); in fact, part-time students currently employed with companies in Research Triangle Park are a growing component through a certificate program. Figure 1 shows the distribution of enrollments by college. Among graduate student enrollments, not surprisingly, 55% were from the College of Agriculture and Life Sciences (CALS), but approximately 17% came from the College of Engineering (COE). Among undergraduates, approximately 50% of enrollments were from CALS and 43% were from COE.

The overwhelming majority of students from COE were from Chemical and Biomolecular Engineering, at both the graduate (75%) and undergraduate (93%) levels (Figure 2).

ACADEMIC FRAMEWORK FOR MOLECULAR BIOTECHNOLOGY EDUCATION

While students can enroll in specific BIT courses to meet educational or research interests, training in molecular biotechnology is officially recognized through campus-wide academic minors and a certificate program. These are described below in brief:

Undergraduate biotechnology minor: open to all NCSU undergraduates, across all colleges, and all majors (see Table 1). The Department of Chemical and Biomolecular Engineering recently developed a biomolecular engineering concentration, which embeds the biotechnology minor into the B.S. degree. In addition to the normal ChE classes and BIT minor, students also take biochemistry and a course in biochemical/biomolecular engineering to earn the concentration.

Graduate biotechnology minor*:* open to all NCSU Master's and Doctoral degree candidates that have taken appropriate prerequisite courses and whose thesis research is in an area of molecular biotechnology (see Table 1). In addition to learning molecular biology techniques through lab courses, students have a unique opportunity to interact with peers in other disciplines. This has led to interdisciplinary research collaborations between groups on campus that may not have otherwise occurred. The interesting thing is that these have been student-driven. For example, food scientists working with veterinary medicine students to develop novel drug delivery methods and chemical biology and chemical engineering students developing novel ways to do microwave-driven biocatalysis. Such interactions would not have likely occurred without the BIT Program.

Graduate Certificate Program in Molecular Biotechnology*:* instituted in 2005 to provide post-baccalaureate students with the opportunity to obtain university-recognized credentials in molecular biotechnology. This Certificate Program is primarily geared toward non-traditional students who have already entered the workforce or are seeking to re-enter the workforce. For example, it provides an excellent opportunity for traditionally-trained, practicing chemical engineers to gain expertise in molecular biology lab skills. NCSU graduate students who are not eligible for the Graduate Minor because their thesis/dissertation work is not in an area of biotechnology are also eligible for the Certificate Program. Participating students must have completed all prerequisites (or their equivalent) to the Core Technologies course (or "Core Course", see below) before acceptance to the certificate program. The minimum requirements for the Core Technologies course are a general biology course that covers gene regulation and DNA replication, and two semesters of organic chemistry. A general microbiology course is recommended but not required. Prerequisites for the coursework electives vary, and those prerequisites may be taken after admission to the certificate program, if necessary. Requirements for completion of the Graduate Certificate Program are detailed in Table 1.

WHAT COURSES ARE OFFERED?

All students begin the program by taking a course entitled: *Core Technologies in Molecular and Cellular Biology*. This "Core Course" is a four-credit course offered in both Fall and Spring semesters that covers the basics of methods in recombinant DNA and protein expression, and serves as the prerequisite for all of our other courses. It is a semester long class that meets each week for a two-hour lecture and a five-hour lab. Students completing this course are awarded our annual BIT Program tee shirt. These usually are designed around one of our new modules and have slogans, such as "BIT happens" or "get bit" (see Figure 3). Following completion of the Core Course (or demonstrating prior equivalent training), students can take advanced laboratory courses, referred to as "modules," which have the same weekly two-hour lecture, five-hour lab periods, but are only 2 credits and last only one-half semester. Students are able to mix and match modules according to their interests. Most of these have only the Core Course as a pre-requisite – this structure creates sufficient flexibility for students campus-wide to pursue the graduate and undergraduate minors. Most of the courses are offered at both graduate and undergraduate levels. In general, students who take courses for undergraduate credit are expected to master techniques and concepts covered in the course, and to be able to analyze data and trouble-shoot experiments gone awry. Students taking the courses for graduate credit have the additional expectation of being able to develop their own experiments and protocols in the area covered in the course. Advanced undergraduates are able to take graduate-level courses by special permission. Brief description of course content is provided Table 2.

WHO TEACHES THE LAB COURSES?

Since we are a Program and not a Department, one of the most common questions asked is: "Who teaches these courses?" The answer is that instructors are recruited from across campus and are at different career stages, but they have certain things in common: 1) they are volunteers and not required to teach our classes; 2) they have expertise in the area of instruction, both conceptual and at the bench; 3) they have a strong desire and ability to teach sophisticated modern biology lab techniques effectively. The majority of our instructors are tenured or tenure-track faculty from a variety of departments and colleges. Their home departments receive "credit hours taught" for the classes they offer, thus the instructors' Department Heads are typically supportive of the arrangement. Some of our instructors are Research Faculty or Research Associates. These are individuals with doctoral degrees whose appointment at the university is primarily research, but who have interest in developing their teaching skills to prepare them for academic appointments. They teach courses on a semester-by-semester basis. We currently have one Teaching Assistant Professor whose appointment is to teach for the Biotechnology Program and to serve as academic coordinator. Finally, we employ one to two teaching postdoctoral fellows (see below).

This instructional model has allowed us to maintain instructors with a high level of energy, expertise, and enthusiasm. One of the benefits to teaching in our program is that all of the students are there because they want to be, thus creating a very stimulating educational environment. Graduate teaching assistants are typically recruited from the labs of the instructors – these are the people who use the techniques and technology on a daily basis and bring a very positive and essential element to the courses. Course evaluations are routinely very positive – *no doubt the product of interested instructors and teaching assistants teaching interested students*.

CHALLENGES FACING CAMPUS-WIDE LABORATORY INSTRUCTION

Campus-wide programs focusing on life sciences face some unique challenges due to their interdisciplinary nature. Discussed below are some that we have faced.

Pre-requisites: In a given class in the NCSU BIT Program, we have students from majors ranging from chemical engineering to plant biology to textiles to microbiology to veterinary medicine. Because we are a campus-wide core laboratory education facility and our mission is to train students from diverse disciplines, it is critical that the prerequisites for our courses not be restrictive. The only prerequisites to our Core Course are a freshman level biology course that covers DNA replication, transcription and translation at a very basic level, and chemistry through the second semester of organic chemistry (2 semesters of general chemistry and 2 of organic). For this reason, background knowledge varies considerably from student to student. Despite this potential problem, the courses have gone surprisingly well. Learning to appreciate how other disciplines approach technical issues can be an education in itself.

Clicker technology: Students with engineering backgrounds tend to have an easier time with quantitative aspects, while students from life sciences majors, such as microbiology and genetics, typically have a better background in biological concepts. We have worked to overcome these differences in a variety of ways. One method we have used in the classroom is the implementation of *clicker technology*. Interspersing clicker questions throughout each lecture in our Core Course allows students to work through questions on their own, without the risk of one student calling out the answer before each student has a chance to think it through. It also helps students not understanding a concept to weigh in on the pace of the instruction without fear of being embarrassed by asking a “simplistic” question.

Aseptic technique: In the lab, in a given semester, perhaps half of the students have already had microbiology with microbiology lab (or cellular biology), and thus only about half have skills in aseptic technique. Time is limited in our core course so that proper coverage of aseptic technique at the level it is covered in general microbiology lab is not possible. We overcome this limitation by partnering students in the lab such that different majors are represented; students can learn from each other. We also limit lab groups to two students so that significant participation is expected from everyone.

Graduate/Undergraduate Mix: Almost all of our courses are dual-level courses, with undergraduate and graduate students in the same classroom and lab. Because many of our courses are resource-intensive “boutique” courses, and because undergraduates and graduate students do need the same set of skills, it makes sense from a budgetary standpoint to combine the levels to reap the greatest benefit from the equipment available. Generally, the students in the graduate and undergraduate level courses have the same lectures and the same laboratory experiences. However, as mentioned previously, the graduate students are expected to perform at a higher level of understanding and proficiency than the undergraduates, as assessed by special assignments given to the graduate students. For example, all students would be expected to apply concepts to solve problems, analyze and trouble-shoot experimental data, and design some of their own experiments, but graduate students might be expected to write a mini-research proposal, designing experiments from start to finish, or to evaluate a journal article for its scientific merit. Although we had initial concerns about grouping graduate and undergraduate students, we have not experienced any significant problems in delivering our courses – not surprising since the lab skills being taught are typically new to everyone.

NEW AND CONTINUING INITIATIVES

The core laboratory education model has also served as a nucleation point for many campus-wide efforts that go beyond our instructional program and a test bed to try new things which would not be possible in a typical departmental setting. Some examples of such activities are discussed below.

Undergraduate Research: There is no doubt that direct involvement in research greatly enhances the undergraduate educational experience (5, 8). The process of researching a topic in the primary literature, designing experiments, implementing those experiments, and analyzing the results is critical for developing the analytical skills necessary to function in the biotechnology sector. The benefits of an undergraduate research experience is reflected in increased undergraduate graduation rates (7), increased rates of pursuit of graduate education (4, 3), and increased interest in science careers (2). The National Academy of Sciences strongly recommends that all undergraduate students be given the opportunity to participate in original research (6). To earn the undergraduate biotechnology minor, students must participate for at least one semester of research on a molecular biotechnology-based project or work for a period of time with a biotechnology company. With respect to the latter, the Research Triangle Park provides ample opportunity for such an experience. We also have two new initiatives directed an enhancing the undergraduate research experience.

First, partnering with the Department of Plant Biology at NCSU, we have received an NSF Research Experience for Undergraduates (REU) grant in the area of synthetic biology in plant systems. The program commences in Summer 2009 and will allow students from universities outside of NCSU to pursue summer research experiences on our campus. All students in the summer program will first complete "biotech boot camp", an accelerated, intensive version of our Core Course, so that they have the proper skills to work effectively in the labs they choose to join on campus for the summer. We think that this preparation will make the REU experience better for both students and mentors since some preparation in molecular biology skills will precede their laboratory experience.

Second, we are in the process of developing an inquiry-guided research course for freshman. In the proposed course, students will isolate naturally-occurring bacteriophage (viruses that infect bacteria, but not humans) from the environment. They will culture, isolate, and titer the bacteriophage (phage), visualize the phage by transmission electron microscopy, and then purify its genome. Students will determine whether the phage has a double-stranded or single-stranded DNA or RNA genome, and then determine the size (number of nucleotides) of the genome. The culmination of this project will be to prepare and present a poster for our annual campus Undergraduate Research Symposium. Our goal is to have students experience the scientific process first-hand early in their college education. This course would be open to students in all majors, with no college-level prerequisite. For non-science majors, the understanding of the scientific method may be more valuable than the facts they could learn in a traditional lecture course. For science majors, we anticipate that involvement in research projects will enhance their performance in science curricula, and will give them confidence to pursue more independent research earlier in their academic careers.

Teaching Postdocs: We also have implemented a Teaching Postdoctoral Program. This is a "win-win" program that gives recent PhD graduates, preferably with a conventional postdoc experience already completed, that also have a strong interest in an academic career, the opportunity to gain significant mentored teaching experience. Since the fellows come "fresh off the bench" with experience in the most cutting-edge technologies, they add an innovative dimension to our program. This fellowship allows for the postdoc to teach a section of the Core Course under the mentorship of an experienced instructor, and then develop and implement his or her own specialized half-semester course. We have "graduated" two teaching postdocs to date, and are working with our third. The two postdocs who completed the program have successfully acquired faculty positions at primarily undergraduate institutions. The new courses that have been added to our curriculum through this program are Mutagenesis, RNA Interference and Model Organisms, and a new course in Protein-Protein Interactions (including the yeast two-hybrid system).

Graduate and Undergraduate Training: The Biotechnology Program also oversees two externally-funded training programs at NCSU and contributes to several others. At NCSU, we have an NIH Biotechnology Training Grant and a Department of Education Graduate Assistance in Areas of National Need (GAANN) Fellowship Program in Molecular Biotechnology. Graduate students supported by these awards complete the graduate Biotechnology minor as well as benefit from other courses that we offer. A new NIH Training Program in Translational Medicine in the Veterinary College will also use elements of our courses for their students. The Microbial Biotechnology Master's program in the Department of Microbiology, which has a strong business focus, incorporates our molecular biology lab courses into their programs. Undergraduate students receiving biomanufacturing training at NCSU through the new Golden LEAF Biotechnology Training and Education Center (BTEC) and the Bioprocessing Science (BBS) major in the Department of Food, Bioprocessing and Nutrition Sciences integrate offerings from the BIT Program into their curricula.

SUMMARY

Thinking "outside the box" can sometimes lead to very effective educational outcomes. Though not without unique challenges, a campus-wide core educational program at NCSU has proven to be an efficient and effective way to deliver cutting-edge molecular biotechnology laboratory courses to students from a wide range of disciplines, including Chemical and Biomolecular Engineering. Housing expensive equipment in a single facility where it can be taken full advantage of, rather than duplicating equipment for teaching purposes in multiple departments, has been a clear advantage in the current budget climate. Furthermore, unforeseen advantages, such as interdisciplinary student collaborations, have arisen. We encourage other institutions to investigate whether this model will work for them and are happy to discuss our experiences with whoever might be interested.

With respect to integrating molecular biosciences into Chemical Engineering (the new "ChE genotype", if you will), laboratory training at sufficiently sophisticated levels that reflect state-of-the-art techniques and skills is crucial. While it may be infeasible for Chemical Engineering departments to provide this training on their own, partnerships campus-wide cannot only provide such opportunities but also create a new paradigm for training our students in the molecular sciences. As we re-think curricular design with biology in mind, it must be done with an eye towards the world of science and technology that our students will be entering: one that is interdisciplinary and dynamic, and one that will care not only about what they know but also what they can do.

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Table 1. Requirements for NC State Biotechnology Minors and Certificate				
Requirement	**Description**	**Undergrad Minor**	**Graduate Minor**	**Graduate Certificate**
General Biology (or equivalent)	Introductory biology course that includes coverage of gene regulation (i.e., lac operon).	X	X	X
Organic Chemistry	Two semesters of organic chemistry	X		
Manipulation of Recombinant DNA (Core Coure)	Intensive molecular cloning laboratory course (undergraduate level)	X		
Core Technologies in Molecular and Cellular Biology (core)	Intensive molecular cloning laboratory course (graduate level)		X	X
Advanced biotechnology laboratory modules	Students choose from courses described below	X (2)	X (1)	X (2)
Research experience	150 hours of biotechnology research on campus or other molecular biology-related research (academic, government or industrial)	X		
Thesis or dissertation	Thesis or dissertation research must utilize molecular biotechnology skills.		X	
Faculty representative	At least one member of the student's thesis/dissertation committee must be a member of the Biotechnology faculty.		X	
Lecture electives	Upper-level lecture course covering molecular biology topics. Examples: Prokaryotic Molecular Genetics, Plant Molecular Biology, Biochemistry of Gene Expression, Genetic Data Analysis, Functional Genomics, and Biochemical Engineering.			X
Ethical Issues in Biotechnology	Ethics and real-world issues in biotechnology and professional ethics.	X		X

TABLE 2. Course Offerings in NCSU Biotechnology Program	
Core Technologies of Molecular and Cellular Biology*	Sub-cloning a gene into an expression vector; screening for positive transformants by a variety of methods including DNA preparation, ligation and transformation, PCR, restriction mapping, colony hybridizations with DNA and monoclonal antibody probes, SDS-PAGE, and Western blotting; and purification of recombinant protein by affinity chromatography.
RNA interference and Model Organisms	History and application of RNAi technology; design of experiments to silence gene expression in various organisms; assessing extent of silencing; use of online tools for design of RNA silencing constructs to knockdown mammalian protein expression; advantages and disadvantages of model organisms; proficiency using *Nicotiana benthamiana* tobacco plants, *Caenorhabditis elegans*, and mammalian cell culture.
Phenotypic Analysis of Transgenic Plants	Phenotypic parameters that can be measured to characterize a mutant or transgenic plant line; methods and technologies that can be used for these characterizations.
Genetic Engineering of Eukaryotic Microbes	Importance of filamentous fungi and yeast in biotechnology and as research tools; manipulation and growth of these eukaryotic organisms ‘in vitro’; genetic transformations of fungi; creation and analysis of mutant strains; expression of heterologous proteins in yeast.
Fermentation of Recombinant Microorganisms	Small-scale fermentations of recombinant *Escherichia coli* and *Saccharomyces cerevisae*; factors affecting gene expression and protein production.
Protein Purification	Chromatography techniques for protein purification, including ion exchange, hydroxyapatite, hydrophobic interaction, gel flitration, affinity; purification tables constructed based on SDS-PAGE analysis, enzyme assays, and protein concentration.
Protein-Protein Interactions	Basic concepts and techniques involved in the study of protein-protein interactions, including the yeast-2-hybrid system, pull-down assays, and immunoprecipitation.
Proteomics	Introduction to the theory and practice of proteomics, analysis of microbial proteomes, statistical data analysis, MS fundamentals.
Mutagenesis	Site-directed mutagenesis by a variety of methods in multiple organisms
Plant Tissue Culture and Transformation	Basic techniques in plant tissue culture and transformation in model plant species and agriculturally important plants.
Animal Cell Culture Techniques	Culture of embryonic stem cells; establishment and maintenance of large-scale eukaryotic cell culture for protein production.
Advanced Animal Cell Culture	Culture of embryonic stem cells; establishment and maintenance of large-scale eukaryotic cell culture for protein production.
Genome Mapping	Basic techniques in genetic and physical mapping; principles of DNA marker development, marker detection, genetic and physical mapping; DNA sequencing
DNA Microarrays	Array design and printing; principles of data analysis and data mining using data acquired from actual experiments; importance of controls and statistical significance; global controls of gene expression.
RNA Purification and Analysis	Isolation of RNA and quantification by spectrophotometry, and analysis by gel electrophoresis; northern blotting and non-radioactive labeling and detection by chemiluminescence.
Real Time PCR	Real-time PCR theory, techniques, machinery, troubleshooting, tools, and advanced protocols, such as multiplexing and SNP analysis
Ethical issues in Biotechnology **	Discuss and debate controversial topics in biotechnology

Computer Analysis of DNA Sequences **	Databases (particularly NCBI/GenBank) for finding homologs of genes and proteins of interest; tools in commonly used DNA analysis software packages.
Research Ethics **	Seminar/discussion of research ethics topics including authorship, animal/human subjects, bioethics, intellectual property, and research fraud
Capstone Biotechnology **	Molecular biotechnology-related research seminars by academic/industrial speakers; stock market competition; interdisciplinary group design project
Professional Development **	Seminar/discussion of topics related to career development, including public speaking, grant writing, CVs, post-doc opportunities, attending scientific meetings, interviewing skills.
**Manipulation and Expression of Recombinant DNA: A Laboratory Manual, 2E* was developed for this course (1) ** Lecture format only	

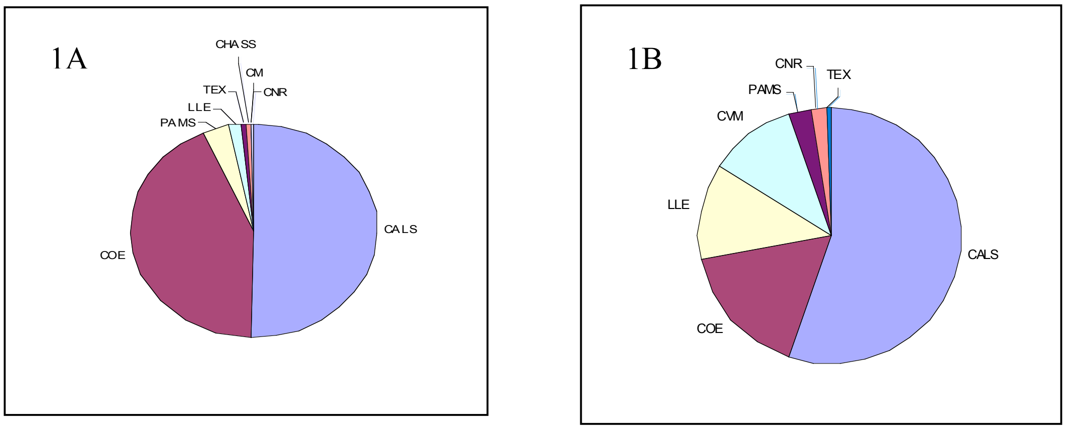

Figure 1. Student enrollments by college. Abbreviations: CALS = College of Agriculture and Life Sciences; COE = College of Engineering; CVM = College of Veterinary Medicine (graduate program, only); PAMS = College of Physical and Mathematical Sciences; CNR = College of Natural Resources; TEX = College of Textiles; CHASS = College of Humanities and Social Sciences; CM = College of Management; LLE = Lifelong Education (non-matriculated students)

1A. Percent of graduate student enrollments by college. CALS 55%; COE 17%; LLE 12%; CVM 10%; PAMS 3%; CNR 2%; TEX 1%.

1B. Percent of undergraduate student enrollments by college. CALS 51%; COE 43%; PAMS 4%; LLE 1%; TEX 1%, CHASS <1%; CM <1%; CNR <1%.

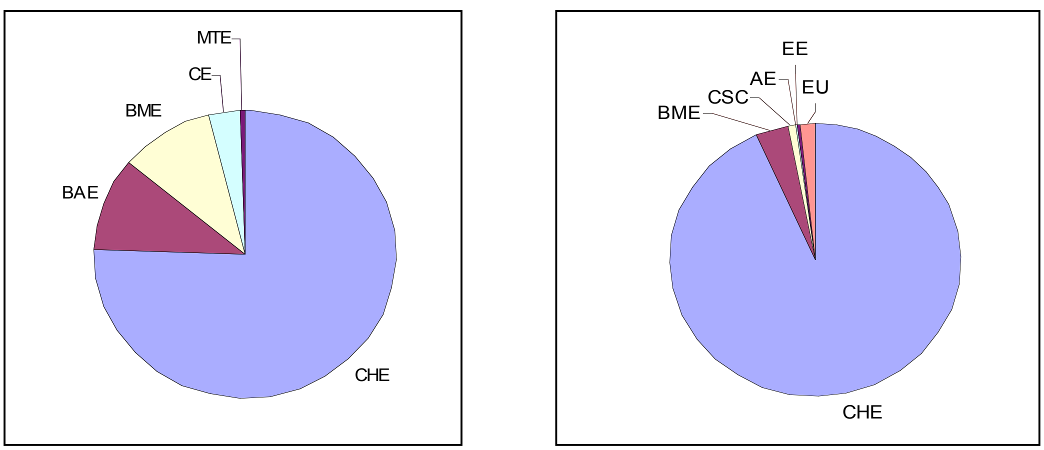

Figure 2. College of Engineering Enrollments. Abbreviations: CHE = Chemical Engineering; BME = Biomedical Engineering; BAE = Biological and Agricultural Engineering; CE = Civil Engineering; MTE = Materials Science And Engineering; EU = Engineering Undesignated; AE = Aerospace Engineering; EE = Electrical Engineering.

2A. Percent of different engineering majors among engineering graduate students. CHE 76%; BAE 11%; BME 10%; CE 3%; MTE <1%.

2B. Percent of different engineering majors among engineering undergraduate students. CHE 93%; BME 4%; EU 2%; CSC 1%; AE <1%; EE <1%.

Figure 3. Biotechnology (BIT) Program T-Shirts. Students successfully completing the Core Course earn the current year's version of the NCSU BIT Program tee shirt. From left to right: Dr. Scott Witherow, teaching postdoc; Rosemary Le, current chemical and biomolecular engineering undergraduate; Dr. Sue Carson, Biotechnology Program Teaching Assistant Professor and Academic Coordinator; Diana Bisbee, chemical and biomolecular engineering graduate (now employed at Biogen Idec); Melissa Cox, Biotechnology Program laboratory manager.