Georgia Institute of Technology
Office of the Provost and Executive Vice President for Academic Affairs

May 30, 2012

Dr. Linda Noble
Vice Chancellor for Faculty Affairs
Board of Regents of the University System of Georgia
270 Washington Street, SW
Atlanta, GA 30334

Dear Dr. Noble:

It is my pleasure to submit this nomination of the Wallace H. Coulter Department of Biomedical Engineering at Georgia Tech for the 2013 Regents' Teaching Excellence Award in the Department/Program Division. This program is an excellent example of the result (really the ongoing process) of an academic unit designing its curriculum and instructional approach to truly focus on student learning and achievement.

While the Biomedical Engineering (BME) program at Georgia Tech is only 11 years old, it is already recognized as the #2 BME program in the country by US News and World Report. The faculty who created this program understood from the outset the particular challenges of integrating core science content with engineering problem solving skills and approaches. They took the innovative approach of designing a problems-focused curriculum that builds in the necessary scaffolding to teach critical thinking skills, communication and teamwork expertise, and an attention to ethics and scientific responsibility. Moreover, with a team of learning scientists on the faculty, they are always working at revising the curriculum measuring student learning outcomes, surveying alumni about the impact of the curriculum on future success, as well as providing support to the faculty to continue to be innovative in their choices of instructional strategies. Departmental resources are directed to ensure that the entering students are taught and mentored in small groups; and all faculty members are involved in working together with these students. In fact, all choices in the design of the core courses are driven by research in how students learn and how faculty can best facilitate that learning.

The Couther BME Department is remarkably successful for such a young academic unit. The graduates from this department have already gone on to be successful in medical school, technology start-up companies, and a host of other career paths. The common denominator has been an ability and an appetite for creative problem solving and a desire to use engineering principles to attack biologically based issues.

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A Unit of the University System of Georgia An Equal Education and Employment Opportunity Institution

I am pleased that our Biomedical Engineering Department is a national leader and is helping shape the future of this important field. Please let me know if you need any further information.

Sincerely,

Rafael L. Bras
Provost and Executive Vice President for Academic Affairs

Riddle: *What do these things have in common: a self-sharpening blade-breaker used in cataract surgery, a running shoe, an energy-efficient LED surgical lighting system that eliminates the problem of shadows over operating tables, a baseball cap that monitors a driver's brain waves and sounds an alarm when she is at risk of falling asleep, an ergonomic rolling barrel for transporting water to unplumbed homes in third-world countries, a patent for a device that delivers stem cells to the heart to aid regeneration of damaged tissue, the Uniformed Services University of the Health Sciences Military Medical School, and Teach for America?*

The Wallace H. Coulter Department of Biomedical Engineering at Georgia Tech welcomed its first undergraduate students in 2001 and, in the ensuing eleven years, has been recognized as the #2 biomedical engineering (BME) program in the nation by U.S. News and World Report's academic ranking—ahead of such prestigious institutions as MIT, Duke, Stanford, and UCSD. Eleven years ago, nineteen students entrusted their futures to a fledgling program and newly-arrived faculty from all over the world. Today those pioneers, the BME Class of 2004, now firmly established in careers of their own, continue to advise the department from which 147 graduated in 2011-12. Eleven years ago, the chair of the undergraduate education committee brought a garden hose from home to run water from a building across the street into the makeshift lab space where his students were conducting experiments. Today our students have the run of classrooms designed for instruction and independent study, a machine shop, a computer lab, a design space, and two common areas, in addition to state-of-the-art research and instructional laboratories. BME's U.A. Whitaker building, built by a private-public partnership, anchors the biotechnology quad on Georgia Tech's campus. Eleven years ago, the department's first teacher stood before Georgia Tech's first BME undergraduate class. Today 44 accomplished faculty members serve 1080 undergraduates as instructors, researchers, entrepreneurs, and learning scientists highly attuned to their responsibilities as mentors to students who are still defining what they want to accomplish with their lives—academically, professionally, and personally—and what it means to be a biomedical engineer. Eleven years ago, in response to recommendations from the Engineering 2020 Education Commission and the Accreditation Board of Engineering and Technology (ABET), the department resolved to develop an instructional curriculum that would not only deliver the requisite content but would also, from the ground up, embrace reform pedagogy in service to the needs of graduates in the 21st century workforce.

Today we have a course of study that addresses the unique challenges of an interdisciplinary field in which several knowledge domains are combined to address medically oriented problems. Today, when the BME Associate Chair of Undergraduate Education hosts a full-day education workshop, 35 of the 44 faculty members (most of the others were out-of-town) voluntarily cleared their schedules of the demands of weighty deadlines in order to learn more about educational philosophy and curricular practices for application in their classrooms. Today our program serves as a model for student-centered pedagogy grounded in the principles of Problem-based Learning (PBL). While many colleges, schools, and classrooms may incorporate some kind of reform pedagogy—most frequently, an isolated instructor's PBL-like or project-based single lesson or module, or sometimes an entire course – our department is a leader in committing significant resources to developing an alternative to lecture-based memorization in an effort to facilitate deep, applicable learning in a collaborative environment and to promote confidence, independence, and reflective learning. The department has "put their money where its mouth is" by providing faculty with development opportunities as well as encouragement and freedom to be boldly innovative in their courses. The department engages students, alumni, and industry experts in evaluation that leads to program modifications, commits dedicated spaces for small-group problem exploration and solving, gives incoming students access to the administration and faculty in an intimate 8:1 ratio for their first required course in the major, and, employs two full-time learning scientists to coach curricular development. As a result, we have developed a suite of reform-based courses that, woven together, form what we call a Problem-driven Learning curriculum. While the department has many noteworthy accomplishments, we feel it is this educational innovation that sets the Coulter Department of Biomedical Engineering at Georgia Tech apart and distinguishes it from its peer institutions.

What is a Biomedical Engineer? Biomedical Engineering (BME) is an evolving *interdiscipline* that has challenged the historical disciplinary barriers between the life sciences and engineering. While BME research activities frequently result in clinical therapies and medical treatments, the field remains intimately tied to the engineering disciplines. Biomedical engineers work on all kinds of devices - from pacemakers to artificial knees - and on a diverse set of research areas ranging from gene therapy for cystic fibrosis, to designing novel imaging strategies for following the progression of infectious diseases, to cancer detection, and to the treatment of sickle cell anemia. Sometimes we like to characterize the BME major as the "liberal arts of science and technology" in an effort to convey the breadth of areas and subjects our students will experience as they move through the major. Graduates of the Georgia Tech BME program have followed career choices as diverse as regulatory agencies like the FDA, medicine, dentistry, public health, hospital administration, healthcare IT, healthcare consulting, medical field engineers, device design, patent law, technology start-ups, entrepreneurship, designing shoes for Nike, and public service through Teach for America. Therefore, it comes as no surprise that as a novel field with virtually no textbooks to date, biomedical engineering education poses special challenges.

> *As an engineer I have a vastly larger body of knowledge to draw from than the majority of my medical school/physician peers, particularly in the area of mathematics and materials science.*
> *- 2007 BME graduate*

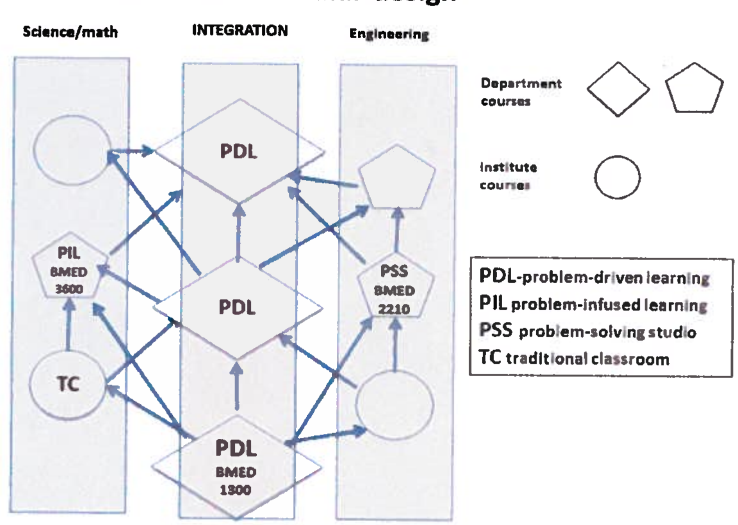
> ***Q:*** *Describe an aspect of your time as an undergraduate student in BME that is the most meaningful to you now.*
> ***A:*** *I am not scared of anything anymore. – 2007 graduate*

Our first challenge is to insure that our BME graduates are ready to solve healthcare-related problems by integrating engineering approaches and bioscience knowledge. They need to be able to analyze biosystems using physical laws and properties, understand pathophysiologies of the human body, and to design healthcare solutions that address disease and disability. They need to understand biomechanics, electrophysiology, and biotransport in organs and tissues. They need to be systems thinkers and accomplished communicators who can work in teams that are eager to translate across disciplinary boundaries, and self-directed learners in a constantly changing field. We have a phrase that characterizes our responsibility as educators and as a department: *Empower students to be agents of their own learning who are fearless in the face of a complex problem.* It is this credo that has inspired the design of our courses and curriculum. Three concepts are foundational to our curriculum development efforts: a ***lattice model*** of curricular design, ***problem-driven learning*** (PDL), and the ***incubator environment*** to nurture the development of both students and faculty. Taken together, these features constitute our educational approach and philosophy.

The lattice model of curriculum development

The first pillar of our educational philosophy is systematic design of a sequence of major courses that mutually inform, support, and preview each other. In the adjacent figure, we depict the overall lattice design of the curriculum. Our students need two kinds of courses: 1) courses that develop deep conceptual understanding in the biosciences, math and engineering, and 2) courses that build interlocking conceptual models and integrate their knowledge and skills from engineering, math and science. The shading emphasizes the two kinds of courses. The three shapes—diamond, pentagon and circle—indicate whether the course is an institute course, a department course focused on science or engineering, or a department integrated course. Moving from left to right, the science/math column include courses in general and organic chemistry,

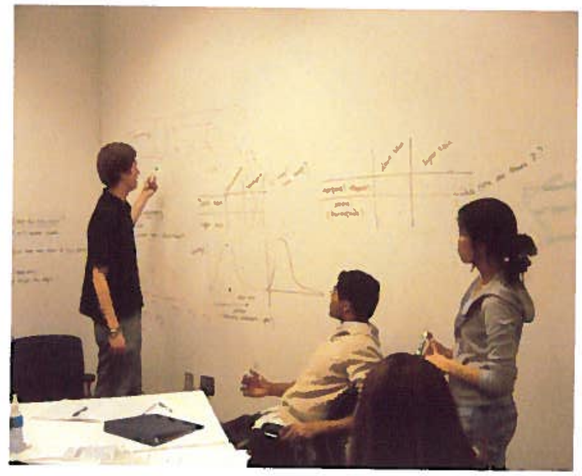
Lattice model of curricular design



cell and tissue physiology, physics and four math courses. The central spine comprises three integrated courses that use a Problem-driven learning approach (PDL). Noteworthy is that the first course in the curriculum (BMED 1300) provides an integrated experience (described below). The right pillar represents the engineering courses in the department and in the Institute. These include biostatistics, biomechanics, statics, principles of mass and energy conservation, and systems modeling. The departmental courses in the outer columns come in three varieties—traditional lecture, problem-infused, and problem solving studio. These approaches are discussed in the following sections. This lattice structure was developed over several iterations of curricular design that involved changing the content of the second course in the central spine to be a design course and developing innovative strategies for engaging students with engineering fundamentals and problem solving (see pages 12 and 13 for more details on how we regularly assess our program).

Problem-driven learning

We use the term *problem-driven learning* (PDL) to describe a suite of courses that have been informed by the problem-based learning (PBL) approach. Originally designed to prepare medical students for the clinic, the PBL curriculum was centered on having small teams of students diagnose the ailments of simulated patients, with the intended outcome that they would develop a deep understanding of the human body and the cognitive practices of diagnosis. Similar to the medical community, we want our BME students to practice a particular reasoning and problem solving strategy referred to as model-based reasoning and, likewise, to anchor their knowledge in rich, complex cases that they have worked on and "solved". The department's Director of Learning Sciences Research, a learning scientist who was a member of the founding faculty in 2000, identified this educational approach as the most viable way to grow integrative thinkers and problem solvers capable of bridging the biosciences, engineering and medicine. Carefully designed, complex, ill-structured problems taken from the real world create the context and the motivation for students to practice the melding of bioscience knowledge with engineering analysis and design. Initially, two courses, Problems in Biomedical Engineering I & II, grounded in the PBL approach, formed the foundation of the department's pledge to implement curricular innovation on a more comprehensive level. Since then, the department has continued to encourage faculty to enact curricular change and the faculty have responded with "Problem-driven Learning (PDL)" innovations that are based on PBL and its two derivatives: Project-based Learning (PjBL) and Product-based Learning (PrBL)



> *PBL helps you think more abstractly and organize your thoughts when dealing with complicated problems. Research is something that has no clear borders or rules; it's incredibly open, just like PBL. Most problems encountered in other classes have a clear set of instructions and are predictable. PBL teaches you how to deal with unpredictability and being really confused, just like research. – 2012 graduate*

In addition to faculty enthusiasm and the department's early- commitment to PBL, five specially designed and dedicated PBL classrooms were included in the BME building's construction, accounting for more than 50% of its instructional space. This purposeful allocation of bricks-n-mortar resources demonstrate the department's resolve to support reform. The PBL environment is a small eleven-by-ten room with four floor-to-ceiling whiteboard walls for student teams to work through ideas, concepts and problem solutions. Schematic and graphic representations (conceptual models) are central to how engineers think and problem solve and these rooms are essential to apprenticing our freshmen students to these representational practices. Even when the spaces are not in use for a specific class, students gravitate to them for impromptu knowledge-building sessions or group review sessions. Students are encouraged to use these rooms 24/7. As a result, on any given day, one can walk into any of these rooms and see the traces of a student-generated, informal organic chemistry review session, conceptual models of an epidemic, or hand-drawn pictures of a neuron.

BME students are immersed in the PDL environment in several learning contexts beginning with the first course in the curriculum, Problems in Biomedical Engineering I (BMED 1300), taken in their freshman or sophomore year. In this course, teams of eight students tackle a series of three carefully designed problems that demand an understanding of how to blend the concepts from the sciences with engineering approaches in problem solving and critical thinking. As an example, the first problem confronts students with the error inherent in cancer screening techniques (see box to right). Students learn about current and future methods and employ engineering analytical methods to evaluate them and make recommendations. Working in teams, students learn to develop decision matrices, scales for evaluation, and create formulas that they apply systematically to each screening strategy. They continue to build these skills as they develop new ones in the next four-week problem-cycle where they design and implement a human subjects experiment to quantify the error in a medical device, and in the final problem where they develop a mathematical model to predict infectious disease propagation and to explore engineering approaches for eradicating it. Through these experiences, students learn how to constrain and define a massively complex problem into a solvable problem. Students are expected to find and decipher peer-reviewed journal articles, learn to evaluate and read research reports, and then apply the relevant information to the problem. The problems lay the foundation for follow-on courses in biostatistics and systems physiology by previewing and contextualizing their future learning in a process called "learn it forward."

Example BMED 1300 Problem Statement
Carcinoma of the pancreas ranks as the fourth leading cause of cancer death in the US. In 2011, of the estimated 44,030 new cases of pancreatic cancer, 37,660 will result in deaths). The overall survival rate at all stages is <1% at 5 years with most patients dying within 1 year. At present there are no reliable screening tests for detecting pancreatic cancer in asymptomatic persons Among healthy subjects, CA19-9, a serologic marker potentially used for screening, has good specificity---85% but nevertheless generates a large proportion of false-positive results (positive predictive power 0.9%) due to the very low prevalence of pancreatic cancer in the general population. The predictive value of a positive test could be improved if a population at substantially higher risk could be identified.

Your team has been selected by the National Cancer Institute to investigate and evaluate current methods for pancreatic cancer screening, including the effectiveness of the most commonly used methods. You are then expected to identify and make recommendations regarding potential future screening strategies, which relative to current strategies enhance sensitivity without sacrificing specificity.

Coming to China [to live for one semester while doing BME undergrad research] and solving problems just for survival has been constant problem-based learning. We didn't come [to China] with a manual. As engineers we view the world in a different way, problem solving is programmed into our minds. We have been presented with many problems and new situations, and we have always used our heads to get through it. I think that BMED 1300 has helped us look past all the confusion of the initial problem that we are given and break it down into what needs to be done. – 2011 graduate

Through a process of iterative design over several years, we have developed a stable core for each of the course's three problems over which we drape a "cover story" so that every semester is different. For example, the Problem 1 cover story can be shifted to a different cancer, organ, or a different disease altogether, such as sickle cell disease, but the problem stays the same at its core: allowing students to explore the physiological mechanisms and systemic nature of the body's organs and the quantitative approaches used by engineers. In the most recent term the class enrolled 168 students, which resulted in 21 teams all working on the same problem at the same time. Every team has a facilitator who meets with the team during the class period, three hours every week, to guide the problem solving process by asking probing questions, challenging the students' assumptions, and nudging them toward asking challenging questions of themselves and the literature. During this immersion with the students, facilitators monitor and assess individual and team skills in four areas: inquiry skills, knowledge building skills, problem-solving skills and team skills. These skills are mapped to behaviors at different levels and displayed in a rubric all students receive the first day of class and which is the basis for grading in the course (see page 15 for the rubric).

The incubator environment

Since the inception of the department, a goal has been to foster the development of novel educational approaches suited to the learning challenges associated with the discipline. Two unique features of the department's environment have been instrumental in achieving that goal which, when taken together, we call the "incubator" environment. First, from its onset, the department committed resources to hiring learning scientists as faculty members. Having learning scientists embedded in the department makes it possible for faculty to have easy and immediate access to experts in teaching and learning. Collaborations between the biomedical engineering faculty and the two learning scientists over the years has stimulated curricular innovation in engineering education. These innovations go beyond the trend to more active learning to new models for faculty-student interactions and the acquisition of knowledge, which we discuss below.

> *PBL in [the research] lab can probably be best seen through my newest dilemma of G2 hepatocyte cell uptake of glycodendrimers. I've never done the experiment before and there are no guidelines for it online. What I've had to do is use the knowledge that I gained… to write a new protocol…. I never would have thought that being an undergrad I would be given so much responsibility, but I am honored at the same time. I definitely feel that having BMED 1300 gave me the courage to voice my ideas, collaborate with others, and be a leader overall.*
> *- 2011 graduate*

The other significant feature is our first PDL course—*Problems in BME I (BMED1300)*–which acts as an accelerator in starting the process of growth and robust development under conditions that are protective, supportive and prepare students to excel and faculty to innovate. Successfully tackling authentic complex problems in their first BME class is instrumental in empowering students to be agents of their own learning who face and engage problems fearlessly. This serves as an important developmental learning ground for our faculty and students. In contrast to the more typical pattern of under-resourcing introductory courses in favor of highly resourced advanced courses, the BME department routinely assigns eleven to fourteen faculty, post-docs and graduate students as facilitators for this one course each semester. Offering students these resources early in their matriculation assures success in subsequent coursework, research, internships, and provides them with the opportunity for practice before entering the work force or graduate school. We believe this focused attention from the department, creating an intimate opportunity to build relationships with peers during what is a difficult course, and consistently personal access to a faculty member shared by only eight students, motivates our students to embrace opportunities for leveraging their acquired leadership, inquiry, and teamwork skills both inside and outside of the classroom. We see evidence of this in the significant number spontaneously participating in undergraduate research (more than 70%), seeking leadership and service opportunities on campus and in the community, and striving for prestigious awards and distinguished recognition (see the "Fact Profile" and "Student Experiences Outside the Classroom" tables on pages 16-17). From our students' first encounter with our program, we work to transform their identities from "engineering student" to "practicing biomedical engineer" by saying, figuratively and literally, that "this is our professional world, these are the ways we approach knowledge in our world, and, because you have chosen to be one of us, we welcome you to fully participate in our world" by treating students more as colleagues than students while remaining mindful of our responsibilities as experts and mentors. Similarly, this first course is instrumental in the development and growth of our faculty. Importantly, all

> *I think one of the greatest things about 1300 is the fact that it forces you to work with your colleagues. Working in the lab, you learn from other people and they learn from you, so much more is accomplished when people work together and build off each others' ideas. Before 1300, I studied alone, and I hated working with other people. 1300 taught me a lot about teamwork and compromise, and I can use these skills not only in lab, but with other students in [different circumstances].- 2012 graduate*

> *I have continually applied the skills that I've learned from 1300 to my research at [another institution] as well as to everyday problems that I come across living in Beijing. I learned from 1300 how to approach and address unfamiliar and complicated problems. Furthermore, taking 1300 taught me that in order to solve problems, it is helpful to "think outside the box" and to sometimes use unconventional methods to solve such problems. In addition to problem solving skills, 1300 taught me the social skills that are an extremely important component of solving real-world problems. Before taking 1300, I was extremely shy and hesitant of asking professors and strangers questions. However, after taking the course, I am now comfortable with asking anyone questions when I need clarification or help.- current BME senior*

BME faculty members, from assistant to full professors, facilitate these student teams on a rotating basis. New BME faculty start their teaching career in the department in this class where they experience a new way of interacting with and guiding students without the overhead of designing such a class on their own. The total learning environment of this first course, which includes problem statements, assessment and scoring rubrics for each problem solution presentation, guidelines for writing reports that are the summation to each problem, and final exam, have been carefully designed. This learning environment allows faculty to effortlessly become participants in taking on the role of mentor, facilitator, and guide, a role that is already familiar to them as directors of their research laboratories but is less familiar to them as teachers and even from their own history as students. Exposure to this new educational approach motivates faculty to discover novel ways of teaching traditional classes, and has resulted in a number of spin-off models that embrace the problem-driven learning philosophy. Three spin-off models from this course include: 1) problem-solving studio; 2) problem-driven laboratory and; 3) problem-infused core class. Each of these models was developed by faculty.

The Problem-Solving Studio.

The problem solving studio (PSS) brings together elements of an architectural design studio with an engineering fundamentals course. The design of this kind of learning environment was first spearheaded by a professor who had previously taught courses using a traditional lecture-based approach but was not satisfied with the results. Inspired and informed by his experiences facilitating BMED 1300, and in consultation with one of the department's learning scientists, the professor created and implemented the "problem solving studio" (PSS) approach, which has now been used in two courses (*BMED 2210: Conservation Principles in Biomedical Engineering*, and *BMED 3510: Biomedical Systems and Modeling*). In a nutshell, PSS is an apprenticeship learning environment that is team-based and student-centered. Students work in heterogeneous teams of two (a "dyad"), at the same table with another heterogeneous group (forming a "dyad of dyads" at the table), to solve problems on large pads of blotter paper. The pad serves as a shared problem-solving space that encourages students to work together to solve problems in a public forum. The tables are on wheels so students can take ownership of their environment and arrange the tables however they want so that they are comfortable and so that the professor and undergraduate teaching assistants can mill about the room easily and efficiently.

The student teams, and the problems they are working on, are the center of attention in PSS, not the professor. Each group is given a set of problems to solve at their own pace. The students work together to solve each problem, constantly explaining out loud to each other their thinking processes. This is a form of 'self-explanation' which is a powerful way to facilitate learning because it prompts students to make inferences beyond the information provided, and because when students compare their understandings and ideas with each other (and with the professor and TAs), they are stimulated to identify and revise any inaccurate or incomplete preconceptions that they may have. The teams and tables are intentionally assigned to include students with heterogeneous skill levels, although students are allowed to request one of the four people that will be seated at their table. Stronger students are paired with weaker students. The stronger students benefit from having to find effective ways to teach their peers, and weaker students benefit from the tutoring they receive from their peers, who often understand more clearly what is confusing about the material and can effectively "translate" what the professor is saying in a way that they can more easily understand. As teams are solving

> *This course (BMED 2210) was extremely helpful as I had never had the chance to fully comprehend how to join principles of physics with chemistry and math.*
>
> *I think this is how education should be from now on; teach the students the basic but essential concepts and then let them connect the dots together. GREAT CLASS.*

problems, the professor and undergraduate teaching assistants (who are students who have already taken this class, done well, and who want to remain involved in this community of learners) stroll about and observe what each team is doing. When teams are stuck, they ask a TA or the professor for help. When the TAs or the professor sees something that a team is confused about, they will visit the table and chat with the team, coaching them with questions. If a pervasive pattern of misconceptions is observed to be held by multiple groups, the professor holds a "just-in-time" discussion with the class. The learning from the "just-in-time" discussions is effective because the students are engrossed in solving a problem and are motivated to listen and participate in the discussion, and then to immediately employ what they just heard and learned. The PSS learning environment is essentially a vertical apprenticeship environment. The professor, who has the greatest level of expertise, mentors the undergraduate TAs who are skilled in the material, but are less experienced. The professor and the TAs also mentor the students, and the students mentor each other via peer-to-peer teaching. The professor and TAs rarely lecture and do not give out answers; rather, they coach with questions, modeling for the students effective metacognitive and self-regulatory thinking processes that facilitate self-directed learning.

Currently, the PSS format of teaching is used primarily to teach an introductory core engineering course called BMED 2210 or "Conservation Principles in Biomedical Engineering". This is a demanding course whose primary purpose is to teach students how to "think like a biomedical engineer" by teaching them how to solve problems while always keeping in mind the rules of the natural universe – the conservation laws of matter, energy, charge, and momentum - while at the same time adhering to community-sanctioned engineering practices such as creating diagrammatic representations of the problems they are solving, reporting answers with units and the correct number of significant figures, and analyzing problems for their 'degrees of freedom' which helps determine whether the problem has a unique answer, and if not, how much and what kind of information is needed to make it have a unique answer. The course follows up on what the students learned about mathematical modeling of infectious diseases in BMED 1300, by teaching them more formally how to represent, analyze, and model complex systems. A specific learning cycle is employed for each new concept or skill that is learned. Foundational lectures are used to introduce students to a new concept in which the professor models for the students how to solve problems using the new concept or skill. Then students work together on problems in the PSS, apprenticed by the professor and TAs. Next they are assigned homework in which they solve more problems on their own, without the professor's or TA's help, during which the level of apprenticeship is faded on that week's concepts. After they turn in their homework they take a formative assessment quiz on the homework material. They work on the quiz on their own for 15 minutes, then with their team for 10 minutes, after which a class-wide discussion is held until all questions are answered. The next class the students take a summative assessment quiz on the material. Students thrive in this learning environment, as evidenced by their comments on the courses that are taught using the PSS approach, which are nearly unanimously positive (see above, embedded in boxes, a selection of comments from recent students).

> *The best aspect of the course (BMED 2210) was the problem-solving studio. I LOVE that I got so much practice and so much feedback during that class time.*
>
> *Working in groups was really helpful because otherwise, I might have been too intimidated to ask questions*

Problem-driven Laboratory. Research labs are problem driven by definition, yet transferring these practices to the curriculum in instructional labs is rare. Typically, instructional cell biology labs tend to be procedures-driven where students are given pre-determined materials for following a set of prescribed steps to complete a standard protocol—for example, an exercise in *doing* a Western Blot or an ELISA, without an opportunity for *thinking about* and *planning for* execution of the technique best suited to the problem and analyzing the data for appropriate conclusions. The lab director determined that the traditional lab format was not relevant to what he knew biomedical engineering to be in the real world. Encouraged by the department's open support for curricular

> *In 3110, my group's personal desire to produce robust, honest, fascinating, and high fidelity results has driven us to explore new experimental designs, do extensive research, produce elegant and sophisticated technical tools (using LabView), and conduct detailed data processing and statistical analysis. – 2009 graduate*

innovation, he worked with the two learning scientists to develop and implement a curriculum using a project-based learning approach and redesigned the BME instructional lab series of two courses—*BMED 3110 & 3610 Quantitative Engineering Physiology Laboratory I & II* -- to make the practices relevant to real BME practices. In open-ended, unscripted labs (versus the typical practice of providing material "kits" accompanied by a "recipe" for enacting a technique), students apply engineering skills and fundamentals to conduct original experiments of their own design. Working in teams of four, students are permitted to come into the instructional laboratory during their weekly assigned three-hour lab time as well as having pass-key access to the lab space on a nearly-round-the-clock basis. In addition to the availability of the lab's equipment and resources, students are encouraged to leverage the knowledge and assistance of the lab director and of the graduate teaching assistants who are trained to serve as facilitators and who are responsible for specific teams. Students are given face-to-face support during class-time and throughout the work day as well as after-hours and weekend access to their facilitators via email and cell-phone. Using cues from research labs, common laboratory techniques were written in a Standard Operating Procedure compiled into an electronic lab techniques book that students are encouraged to use as an additional resource. This resource includes the initial basic lab techniques to get started in the lab setting such as counting cells or measuring total protein content in a sample. However, identification of the right tools, techniques, and materials for the job is left to the students to determine from the project that they have identified and the existing literature.

To have the freedom to do my own experiments at my own rate made me enjoy this class so much more than any lab class I have had here at Tech.

In this two-semester series, the first semester (BMED3110) has a prescribed number of problem modules leading to a video presentation of each team's human subjects experiment. They devise and run an experiment using a simulation to model a physiological problem from everyday life such as examining the effect texting has on reaction times while driving or exploring the role of handedness on balance.

I had a moment near the end of BMED3610 [Quantitative Engineering Physiology Laboratory II Instructional Lab] where I realized that this class is the culmination of many of the concepts which I studied as an undergraduate BME at GT. I performed cellular experiments (which I also did in undergraduate research), statistical analysis (used in math and statistics classes), and added my senior design device to the final module (mechanical design, anatomy and physiology, physics) all while continuing the research aspects which are part of 3610's structure.

In the second semester (BMED3610) students identify a problem for exploration on the bench top. The problem could extend an existing research problem identified in the literature, or a problem that resonates with the students on a personal level, or it might be an extension of their undergraduate research experiences, or it might come from clients that they are working in their capstone senior design class. Students begin each module with a pre-lab presentation of their research proposal during which they identify materials within a budget, instrumentation required to complete the module, and areas where they predict they may require more mentorship. Facilitators are encouraged to allow students to make technical but not strategic mistakes. For example, students are required to have proper positive and negative controls in their experiments but allowed to err during a western blot as long as their controls gave them clues about where the error might have occurred. Report discussion grades are weighted heavily in the final grading to encourage a revisit of procedures for reflection on causes of error and best practices for repeating the experiment or predictions for replication.

We continue to assess the instruction and learning in the instructional labs using both qualitative and quantitative methods, making adjustments every semester based on what we observe and the outcomes of our evaluations. For example, during a formal group interview conducted by one of the learning scientists, students who had less research lab experience mentioned a desire for more basic training. So the lab director developed a series of informal tutorial sessions that allowed students to casually drop by at will on Friday afternoons for guided practice on such

The most important thing I appreciate [about the instructional lab courses] is the extensive amount of time [the lab director] puts into helping his students get their projects up and running, troubleshooting their projects, and trying his best to provide us with all materials we need for any project our heart desires. He really pushes us to be the best we can be and he is enthusiastic about our projects.

elementary techniques as pipetting, measurement, or whatever topic of the day a particular student might find useful. One consistent observation across the five years since these courses have been offered is that this type of reflective learning/teaching is time consuming for both the students and the instructors. Traditional lab instruction methods are easier—everyone knows what to expect, everything is controlled and predictable, class after class, semester after semester. Nevertheless, our commitment remains steadfast to put in the extra time and energy required to create an "options wide-open" laboratory experience for our student and for providing them with the guidance they need, wherever their projects may lead. We are invigorated by the knowledge that our students' learning is more robust than that of a control group against whom we compared the curriculum outcomes in the prior (traditional) course design, the quality of the students' performance, and acknowledgement from students who recognize and appreciate the power of independence and confidence in the lab setting. We are inspired to be continuously reflective in our teaching practices by the insights that students offer (see embedded quotes in this section of the text).

> *These classes were A TON of work, but they were worth it. They were my favorite classes I've taken.*

The Problem-infused Core Course Cellular and molecular biology is a content domain central to modern-day biomedical engineering. Traditionally, this content is taught in lecture-based settings with large class sizes. Responding to their observations of student engagement and the relationships they built with students while facilitating the first PDL course (BMED1300), the professors who were charged with responsibility for our cell biology course-- *BMED 3600: Cellular and Molecular Biology*—consulted with the department's learning scientists for help. "I know that the students must have been bored because I have just bored myself with my own lecture," cried one of the exasperated professors after delivering a lecture, "there has got to be a better, more interesting way to teach this material!" Thus, the traditional lecture-based course was replaced with a curricular innovation grounded in a problem-based learning approach. While the primary goal was to make the curriculum relevant to the content and practices that students—taking the course as they near graduation—would need in the real world, the professors also wanted to facilitate a more meaningful relationship with students and between students than afforded by large classes sitting in lectures.

> **BMED 3600 Problem Statement**
> What makes the problem of cancer so difficult to solve is that the process of cell division and death can be controlled at a number of levels, including mutations that affect transcription and translation of normal proteins at normal levels, protein trafficking, and receptor-ligand and cell signaling alterations. Aberrations in these cellular control systems can propagate into other aspects of the cell and its microenvironment including cytoskeletal changes, remodeling of the extracellular matrix, and signaling to other cell types. GE Healthcare has hired your small consulting firm to develop and propose a new potential cellular/molecular strategy for the ***detection of primary pancreatic cancer cells and/or the detection of metastasis.***

Course content was divided into two main components covering (a) basic "parts-and-pieces" of cell biology and (b) "dynamics/how it works" aspects of cell biology. Students engaged with the same science content topics repeatedly throughout the course, each time at increasing levels of complexity, moving from novice understanding to something closer to expertise during the semester. Three practices were combined to convey the course content: (a) critical reviews of recent peer-reviewed journal papers, (b) a team-based self-directed element grounded in PBL principles and practices, and (c) foundational lectures on the course content. Each week's content was integrated across the three pedagogical methods. In the problem-solving component, groups of 4 students were tasked with posing meaningful and scientifically accurate solutions to contextualized (real world) biological problems at the cell and molecular level. The problems extend for 6 weeks to allow students to develop a strong and deep knowledge of the biology of the problem they are challenged to solve. The content thread of a disease explored in the first PDL course (BMED 1300) is leveraged to allow students to take their growing expertise with the content developed in coursework since that first semester

> *I've never been really confident about reading and understanding technical papers. I used to find them intimidating because of their length and difficult vocabulary. I think the best thing I got out of this course was the paper critiques because it forced me to read and write about a technical paper in a relatively short amount of time. I realized from this that technical papers aren't as horrific as I've imagined them to be. From now on, I'm going to be using the same analyzing techniques that were implemented in the class whenever I have to read technical papers!*

in BMED1300 and employ material learned in this course where the original task of identifying screening methods in BMED1300 becomes *developing* new screening strategies in BMED3600. Students are required to research the topics in depth and combine engineering approaches with basic cell biological knowledge to present an innovative approach or solution to the problem. These presentations serve as a series of mini-lectures to the whole class which expose students to a number of complex biological concepts and varied approaches to applying biological knowledge within the context of an engineering design problem. A weekly lecture provides students with the formal course content knowledge required to have a foundational understanding of the principles they are employing in the problem-solving module. Additionally, students are coached in the value and methods of critically reviewing scholarly literature in order to engage them with the most recent discoveries in this rapidly developing field.

> *I think the group projects were more useful in teaching us how to learn material without being spoon-fed the information. The vague nature of the problem statement forced us to take a more investigative approach.*

Analysis of data from the original course design allowed us to identify specific adjustments that would make the course structure more manageable for the students and make the goals more transparent. We learned that it was naïve to expect students to intuit the purpose of the elements of the pedagogy. Thus, in subsequent iterations we adapted the course using lessons learned from the participants. We continue to evaluate and iterate in an effort to keep it fresh and meaningful for both the students and the instructors. The students themselves encourage us with their own awareness of the value of the learning structures we used, as evidenced by their comments (see embedded quotes above).

Assessment: Substantiating Reform Pedagogy in BME curriculum

Program Assessment: Outcomes-based and Standards-based

The Coulter Department's B.S. degree program has been certified by the Accreditation Board of Engineering and Technology (ABET) since 2004. For us, the accreditation process is not particularly stressful or difficult because the data we collect to achieve and maintain accreditation is the same data that we use to inform and substantiate curricular innovation every day, every semester, and across the eleven-year journey that has taken us from the new-kid on the block to being ranked second by our peers.

ABET is a federation of over 30 professional and technical societies. These societies and their individual members collaborate to develop quality standards, known as ABET Criteria, on which review teams base their evaluations of applied science, computing, engineering, and technology programs. According to ABET criteria, engineering programs should prepare graduates to apply knowledge of mathematics, science, and engineering; design and conduct experiments, as well as to analyze and interpret data; identify, formulate, and solve engineering problems; understand professional and ethical responsibility; communicate effectively; function on teams; understand solutions in a global, economic, environmental, and societal context; recognize the need for and engage in lifelong learning; design a system, component, or process to meet realistic constraints; develop a knowledge of contemporary issues; and use the techniques, skills, and modern engineering tools necessary of engineering practice. Programs undergo accreditation at least every six years to ensure that they continue to meet quality standards set by the profession. As part of the accreditation procedure, an internal evaluation and self-study report document how well the program is meeting the criteria in multiple areas (i.e., students, curriculum, faculty, administration, facilities, and institutional support). The ABET evaluation team then conducts a four-day campus visit during which they interview students, faculty, and administrators as well as review course materials, student projects, and sample assignments. Mindful of the comprehensive nature of the accreditation procedure, the ABET criteria serves as a guide for our overall program as well as for instruction. It actually predisposes us to be constantly cognizant of how we will measure and account for what our students do while in our program and what evidence best substantiates our observations of their successes.

The focus of ABET accreditation activities are program educational objectives (PEO), e.g., what graduates are prepared to achieve, and program outcomes (PO), e.g., attributes students attain before graduation. These are designed to serve as guideposts for continual improvement processes. Multiple sources of information are used to inform decisions regarding program improvements. Alumni surveys are the primary source informing actions related to PEO, while rubric-based assessments of student performance in their coursework are the primary sources informing actions related to PO. Multiple groups are involved in continual evaluation including the department's external advisory board, student advisory board, and the BME undergraduate committee.

The results of these continuous improvement processes have been three major changes made to the structure of the curriculum, both in terms of courses required and prerequisite structure, over the past decade. The two primary forces behind the most recent changes, which became effective in the fall semester of 2011, were the results of an extensive, in-house survey of alumni from the classes of 2004-07 conducted in 2010 (the elapsed time allowing them to become established in their careers) and the new Georgia Tech strategic plan's challenge to provide increased opportunities for interdisciplinary education through flexible, student-focused curricula. Data from the alumni survey, which had a remarkable 66% response rate, identified topics in several required courses that proved to be of minimal benefit to the majority of the alumni. The survey also revealed that the alumni were choosing to pursue careers in a wider variety of fields than was anticipated when the original curriculum was designed in 2001. These findings led to the decision to remove five required courses from the curriculum and replace those hours with a new requirement for the students to obtain a minor. This will allow students the opportunity for increased breadth in their studies, as they may choose any of the over 40 minors offered at Georgia Tech.

Curricular Innovation: Formative and Summative Assessment

As a part of our department's self-conscious focus on pedagogical practice, we have IRB approval for an on-going, unfunded study of the impact of PBL in the BME curriculum. As a result, we are able to run our classroom innovations as research since PBL provides the theoretical underpinning on which they are based. This means that, for each course, we have the ability to compile a rather rich data set from pre-, mid-, and post-course surveys as well student-generated embedded artifacts (i.e., homework assignments, exams, lab notebooks, presentation score sheets, reports, posters, design-n-build projects, etc.), interviews, and ethnographic observations in order to develop a holistic understanding of the classroom and the impact on student learning and development. In addition to using the student-generated artifacts as summative assessment of student performance for grading and student self-reflection, it provides us with formative data we use to tweak subsequent iterations of the courses over time. Our assessment contains both qualitative and quantitative data giving us a robust understanding of the phenomenon. The presence of cognitive scientists on our staff supports this depth of data collection and reflection because they collaborate with our primary faculty who are, after all, engineers without backgrounds in educational theory. Our primary faculty are therefore provided with a great deal of support to identify best practices, design curricular innovation, and leverage the implementations as research projects that can then be shared with the larger engineering education community at conferences and in journal papers. In addition, the lattice model (page 4) affords us an opportunity for collecting longitudinal data as students wend their way through the curriculum. Because the first PDL course—BMED1300 – is taken by second-semester freshmen and other PDL courses are grounded in its principles and incorporate its practices, students taking later classes offer us insight into what persists over time as well as how perception changes with maturity.

> *Sometimes it is really hard… to see the connection between a specific class and what I'm researching in lab, but that doesn't mean there doesn't exist one. I have taken both 1300 and 2300, and I feel like 1300 teaches the critical thinking process while 2300 introduces the necessary skills. 1300 has taught me how to do research, how to work in a group, and how to tackle a problem from beginning to end. – A student reflection from BMED3600*

To provide an example of how our we develop assessment instruments fitted to the needs of these unique classroom enactments, we attach the rubric used in BMED1300 (see page 15). Students are given this instrument on the first day of the semester and it is revisited repeatedly throughout the term serving as an assessment tool used by the facilitators as they coach each student in the four areas of participatory structures and also as a self-assessment tool used by students to strategically target behavioral change. The rubric operationalizes the skills we want our students to continuously develop and improve: teamwork, problem solving, inquiry, and knowledge building. The rubric is designed to capture change over time with novice (poor) behaviors carrying less weight than expert (exceptional) behaviors that we know require focused practice and coaching.

Conclusion

Since the Coulter Department of Biomedical Engineering at Georgia Tech opened its doors, it has been on a deliberate path to develop an educational program that will serve as an example of how engineers can be reflective, responsive innovators in education. The founders, advisory board, administration, and faculty hold a shared vision of creating a rich culture of learning that is learner-centered, collaborative, professionally relevant, and academically rigorous. While pleased with our US News & World Report ranking, we are most proud of our students and graduates who embrace their responsibilities as scholars and citizens; biomedical engineers who are independent, self-motivated, confident *agents of their own lifelong learning who are fearless in the face of a complex problem.*

To return to the riddle: what is the common element between a self-sharpening blade, a running shoe, an energy-efficient LED surgical lighting, a brain-wave monitor, sleep-alerting baseball cap, a third-world water barrel, a device for stem-cell implantation to aid regeneration of damaged heart tissue, the military's medical school, and public service teaching?

Answer to the riddle: *Students or graduates of The Coulter Department of Biomedical Engineering at Georgia Tech—and the department and faculty that nurtured them.*

Faculty teaching awards and other noteworthy awards and accomplishments

Barbara Boyan: Mentor of the Year Award from the American Association for Dental Research (2000); Appreciation Award, Sophomore Dental Student Summer Research Fellows (1985); Professor of the Year from the BME undergraduate students (2007)

Edward Botchwey: Excellence in Diversity Fellowship University Teaching Fellowship

Robert Butera: CETL Junior Faculty Teaching Fellow, 2000

Melissa Kemp: Georgia Tech Outstanding Junior Faculty Undergraduate Research Mentor (2011)

Joseph Le Doux: Nominated for the Goes the Extra Mile Award, GT Student Ambassadors (2011); Excellence in Teaching Award, BMES, Georgia Tech (2011, 2012); Above and Beyond Award, BMES, Georgia Tech (2009); Hesburgh Teaching Fellow, Georgia Tech (2007); Educational Partnership Award, Georgia Tech (2005)

Wendy Newstetter: Georgia Tech curriculum innovation award (2012)

Manu Platt: GT - BMES Over and Above Award; Junior Faculty Undergraduate Research Mentor Award

Steve Potter: Howard Ector Outstanding Teacher Award, 2011

Lena Ting: 2004 Teaching Excellence Award, Biomedical Engineering Student Advisory Board, Georgia Institute of Technology 2006 Junior Faculty Teaching Award, Georgia Institute of Technology 2007 Above and Beyond Award

Johnna Temenoff: Center for the Enhancement of Teaching and Learning CETL/BP Junior Faculty Teaching Excellence Award, 2010; GT Women in Engineering Faculty Teaching Award, 2012; Selected to attend 2010 National Academies of Engineering Frontiers of Engineering Education Conference (December 2010); American Society of Engineering Education Meriam/Wiley Distinguished Author Award, 2010

May Wang: Georgia Tech Outstanding Undergrad Research Faculty Mentor (2005)

Cheng Zhu: Led the department's effort to establish a Joint PhD Program in Biomedical Engineering with Peking University (China) in 2009

GT-BMED1300 ASSESSMENT RUBRIC

	EXCEPTIONAL/Expert (A)	PROFICIENT (B)	FAIR (C)	POOR /Novice(D)
INQUIRY SKILLS	Actively looks for and recognizes inadequacies of existing knowledge Consistently seeks and asks probing questions Identifies learning needs & sets learning objectives Utilizes advanced search strategies Always evaluates inquiry by assessing reliability and appropriateness of sources	Recognizes inadequacies of existing knowledge Generally asks probing questions Utilizes appropriate search strategies Mostly evaluates inquiry by assessing reliability and appropriateness of sources Utilizes effective search strategies	Occasionally claims areas of inquiry but mostly takes what's left Occasionally asks questions Uses search engines like Google to find easily available information of questionable reliability/ appropriateness	Takes whatever is left for inquiry Rarely, if ever asks questions Fails to recognize limits of understanding/knowledge Fails to assess the reliability or appropriateness of sources Demonstrates unsystematic search strategies
KNOWLEDGE BUILDING	Thoroughly digests findings and communicates effectively to self and others Consistently identifies deep principles for organizing knowledge as evidenced in research notebook Constructs an extensive and thorough knowledge base in all problem aspects Continually asks probing questions	Digest findings and communicates to self and others Identifies deep principles for organizing knowledge Constructs a thorough knowledge base in most problem aspects Asks probing questions	Reads inquiry results to group without thorough understanding of material Learns own area of inquiry but not those of others Occasionally asks questions	Fails to understand or be able to communicate inquiry findings Rarely if ever asks questions Fails to use the problem to develop/enhance BME knowledge
PROBLEM SOLVING	Repeatedly explores the problem statement to identify critical features Defines/redefines the problem and identifies problem goals Breaks problem down into appropriate parts Identifies and defines appropriate criteria Frequently uses white boards to assist in problem solving Consistently applies inquiry results to problem Develops models and hypotheses	Explores the problem statement to identify critical features Seeks to understand problem goals Identifies criteria Uses inquiry in problem solving Uses white boards to assist in problem-solving Occasionally develops models/ hypotheses	Relies on group to identify critical features Lets group identify problem goals and then follows along Sometimes applies inquiry to problem solving	Fails to define problem Articulates no problem goals Never uses the white boards Fails to apply inquiry to problem Never suggests a plan of attack Fails to develop analytic framework
TEAM SKILLS	Actively listens to and encourages team members Willingly foregoes personal goals for group goals Always avoids contributing excessive or irrelevant information Expresses disappointment or disagreement directly to team members when warranted Finds ways to gives emotional support to others on the team Clearly demonstrates enthusiasm and involvement Monitors group progress and facilitates interaction with other members Facilitates a distributed leadership among team members	Supports group goals Avoids contributing irrelevant information Expresses disagreement directly Gives emotional support to others Demonstrates enthusiasm and involvement Facilitates interaction with other members Completes tasks on time	Goes along with the group Follows but does not lead Avoids confrontation even when angry or frustrate Engages in limited interaction with other members Occasionally comes unprepared with no explanation Leads but has trouble giving leadership to others in the group	Does not help in developing team skills Gives no emotional or intellectual support to team Lets group down by failing to complete tasks Observes silently contributing little to process Shows little or no enthusiasm or involvement Talks over others and fails to relinquish the floor Takes on too many responsibilities thereby disenfranchising other team members

Fact Profile, The Wallace H. Coulter Department of Biomedical Engineering

Georgia Tech BME Department	• Housed in the U.A. Whitaker Building in the Bio-tech quad on the campus of Georgia Tech in midtown Atlanta • Partnering faculty and research facilities at Emory University • Ranked #2 nationally (US News and World Report)
Faculty	• Total: 44 (Tenure track 9; Tenured 32; Academic professional 3; Female faculty 10). Endowed chairs: 10
Noteworthy Faculty Accomplishments	• 215 external grants totaling over $55 million (2010-12) • 5 NSF Career Awards totaling over $2 million (Note: NSF Career Awards require a strong educational outreach component) • 2012 Curriculum Innovation Award – Dr. Newstetter • 2012 W. Howard Ector Outstanding Teacher Award – Dr. Potter • 2012 Sustained Research Award – Dr. Boyan • 2012 Outstanding Undergraduate Research Mentor - Dr. Platt
2011-12 Undergraduate Students	• Number of undergraduate students: 1080 • Percent women: 42% • Percent underrepresented minorities: 11% • Percent Georgia residents: 60%
2011-12 Graduate students	• Number of graduate students: 156 • Percent women: 44% • Percent underrepresented minorities: 6% • Percent Georgia residents: 12%
2012 Examples of Noteworthy Student Accomplishments (Undergraduate students only)	• Phi Kappa Phi Award (GT's highest academic honor) – Bilal Bari • Helen Grenga Award (GT's top female engineer)- Katy Hammersmith • College of Engineering Research Award - Chun Yong • Barry M. Goldwater Scholarship - BinBin Chen • Whitaker Fellowship - Katy Hammersmith • 1st Place Inventure Prize (GT's largest innovation competition for undergraduates) - Team ReHand - software-assisted home-use hand rehabilitation device (4 BME undergraduates) $15,000 plus patent filing valued at approx. $20,000 = $35,000 • People's Choice Inventure Prize - Team Cardiac Tech - chest retractor for bypass surgery- (3 BME and 2 ME undergrads) $5,000 • 1st Place Georgia Tech Business Plan Competition (best exemplar of strong leadership and business skills) - Team MAID Magnetic Intubation Device (4 BME undergrads)- First undergrad team to win 1st Place in history of this competition; $42,500 • 1st Place DMD Competition (the world's largest medical device competition)- Team MAID Magnetic Intubation Device $500 • President's Undergraduate Research Awards (PURA): 91 (of 277 awarded campus-wide) • Petit research awards: 14 (of 19 awarded campus-wide) • Research travel awards: 5 (of 9 awarded campus-wide)

Student experiences outside of the classroom

Research	• Percentage of students who have worked at least one semester in a research lab: o 4th year students: 72% o 1st year students: 15% • Percentage of students who were working in a research lab last semester (spring 2012): o 4th year students: 43% o 1st year students: 14% • Average number of hours per week students work in the lab: o 4th year students: 9.1 o 1st year students: 10.6 • 40% of our 4th year students who are working in lab have presented posters of their work at national conferences • 48% of our 4th year students who have worked in a lab are a co-author on at least one peer-reviewed publication
Study and work abroad	• 18% of our students have studied abroad. Breakdown by class: o 4th year students: 22% o 3rd year students: 27% o 2nd year students: 14% o 1st year students: 7% • 4% of our students have worked abroad • 26 students have conducted research in foreign labs with international collaborators
Leadership and engagement in campus organizations	• 63% of our students (Spring 2012) were actively involved in one or more campus organizations • 31% of our students (Spring 2012) occupied a leadership position in one or more campus organizations
Leadership and engagement in BME organizations	• The Pioneer Monthly Newsmagazine (distributed in print and online)- staff of 49 students (editors, writers, webmasters, layout, photographers, etc); 11 faculty advisors • Biomedical Engineering Society (BMES)- 130 active members • Biomedical Research Opportunity Society- 50 members (Winner of GT's Best New Student Organization 2011)
Service	• Engineering World Health (EWH) • Grady Hospital Volunteers • Founders of the Saturday Morning Pancake Breakfast for the Homeless are BME undergrads • Graduates joining Teach for America before Med School
Internships and co-ops	• 42% of our 4th year students have internship or co-op experience: o 4th year students: 42% o All "non-1st year" students: 27%

Summary of undergraduate student graduation results, 2009-2011

	2009			2010			2011		
	Female	**Male**	**Total**	**Female**	**Male**	**Total**	**Female**	**Male**	**Total**
Highest honors	13	26	39	20	24	44	15	29	44
High honors	5	14	19	11	12	23	8	8	16
Honors	8	10	18	13	15	28	9	12	21
Passed	19	40	59	24	36	60	28	37	65
Total	**45**	**90**	**135**	**68**	**87**	**155**	**60**	**86**	**146**
GPA	*3.21*	*3.16*	*3.18*	*3.25*	*3.14*	*3.19*	*3.18*	*3.24*	*3.22*
URM	4	4	8	8	9	17	9	4	13

Summary of undergraduate job status, 2009-2011

	2009		2010		2011*	
	#	%	#	%	#	%
Industry	59	44	69	44	45	31
Graduate school	26	19	26	17	33	23
Medical school	22	16	26	17	10	7
Other	13	10	12	8	14	10
Unknown	15	11	22	14	44	30
Total	**135**		**155**		**146**	

*our information for last year's graduates is still not complete, particularly with respect to how many of our students were accepted to medical school

Faculty accomplishments in teaching and education research

NSF Career Awards won by our faculty

Several BME faculty won the National Science Foundation (NSF) Career Award. This prestigious award is provided in support of junior faculty "who exemplify the role of teacher-scholars through outstanding research, excellent education and the integration of education and research within the context of the mission of their organizations."

Younan Xia, Ph.D. Award title (1999): *Nanostructured surfaces and materials.* Project summary: This project led to the development of two new university-level courses. One course presented an overview of the principles and recent activities in nanoscience and nanotechnology. The second course was in material chemistry. As part of this award, Dr. Xia supervised three high schools students working in his lab, each of whom went on to college (Princeton, University of Chicago, and UC Berkeley) to major in science or engineering.

Joseph M. Le Doux, Ph.D. Award title (2001): *Engineering Recombinant Lentiviruses for Cystic Fibrosis Gene Therapy.* Project summary: This award focused on the development of problem-based learning (PBL) exercises that introduced secondary school students to problem solving and technological approaches used in the field of gene therapy. The work was conducted as an outreach program in collaboration with middle school and high school biology teachers. Dr. Le Doux and his high school teacher collaborator, Amanda Lockhart, won Georgia Tech's Educational Partnership Award in 2005. They published their work in The Science Teacher, December 2005 p29-33.

Julia Babensee, Ph.D. Award title (2003): *Innate and Adaptive Immunity in Tissue Engineering*
Project summary: This award supported the development of a new undergraduate cell and tissue engineering laboratory course that integrated hands-on training in cell and tissue engineering laboratory techniques with current concepts in the field.

Robert Butera, Ph.D. Award title (2005): *Functional replacement of neural tissue in a model organism – research and education in neuroengineering.* Project summary: The goal of this project was to integrate critical thinking concepts into undergraduate education and to develop new methods for explaining hard-to-understand physiology concepts.

Johnna Temenoff, Ph.D. Award title (2008): *Heterogeneous cell carriers to promote gradiated tissue formation under mechanical loading – an integrated education and research study.* Project summary: In this project, modular curriculum materials for university students were developed to facilitate ethical discussions of recent controversies pertaining to biomaterials used in medical devices, and included case studies on biomaterials failure for use in classroom discussions.

Charles Kemp, Ph.D. Award title (2012): *Haptic interaction for robotic caregivers*
Project summary: Dr. Kemp plans to incorporate research results in his biomechanics class and graduate course on haptics, and will then adapt the material to teach people around the world about these topics and robotics using the methods and tools of Khan Academy.

Additional recent teaching and education grants awarded to our faculty

- NSF REESE (#0106773): "ROLE: Biomedical Engineering Thinking and Learning: The Challenge of Integrating Systems and Analytical Thinking:, (2001), PIs: Nancy Nersessian, PhD; Wendy Newstetter, PhD
- NSF REESE (#0411825): "Laboratory learning: Model-based reasoning in biomedical engineering research and instructional laboratories", (2004), PIs: Nancy Nersessian, PhD; Wendy Newstetter, PhD
- NSF EEC (#0647915): "InTEL: Interactive Toolkit for Engineering Education", (2007), PIs: Janet Murray, PhD; Sue Rosser, PhD; Laurence Jacobs, PhD; Wendy Newstetter, PhD;
- Procter & Gamble Higher Education Grant Program: "Assessing curriculum innovation: Problem-based learning in biomedical engineering", (2008), PI: Barbara Burks Fasse, PhD
- NSF SES (#0832912): "Ethically Contentious Research and Innovation: An Interdisciplinary and Interinstitutional Experiment in Ethics Education and Assessment", (2009), PIs: Roberta Berry, PhD; Wendy Newstetter, PhD; Robert Kirkman, PhD; Kathleen Kinlaw, PhD; Edward Queen, PhD.
- NSF REESE (#0909971): "Becoming a 21st Century Scientist: Cognitive Practices, Identity Formation, and Learning in Integrative Systems Biology", (2009), PIs: Nancy Nersessian, PhD; Wendy Newstetter, PhD
- NSF IRES (#0927555): "US-China Undergraduate Research Experience in Biomedical Engineering (CURE)", (2009), PIs: Paul J. Benkeser, PhD; Cheng Zhu, PhD; Barbara Burks Fasse, PhD
- NSF CCLI (#1022778): "Biologically Inspired Design: A novel interdisciplinary biology-engineering curriculum", (2010), PIs: Jeannette Yen, PhD; Marc Weissburg, PhD; Ashok Goel,, PhD; David Rosen, PhD; Wendy Newstetter, PhD
- NSF REESE (#1109309): "Transforming text to diagram: investigating and helping students develop key cognitive strategies for solving engineering problems", (2011), PIs: Joseph M. Le Doux, PhD; Wendy Newstetter, PhD
- NSF DUE (#1147341): "Building a new community of practice: Translating what we know from research and from the field into planning 21st century learning environments", (2011), PIs: Jeanne Narum, PhD; Wendy Newstetter, PhD

Selected recent presentations and publications on teaching and learning

Newstetter, W. & Benkeser, P. (2002) Learning Assessment in Problem-based Learning for BME Students. *2002 ASEE.Conference Proceedings. [CD–ROM]. Toronto, Canada.*

Newstetter, W. Neresessian, N.J., Kurz-Milcke, E.,Malone, K.R. (2002). Laboratory learning, classroom learning: Looking for convergence/divergence in biomedical engineering. *Proceedings of ICLS Conference 02. AACE.*

Newstetter, W., Kurz-milcke,E., & Nersessian, N. (2004) Agentive learning in engineering research labs. *Proceedings of 2004 FIE Conference. [CD–ROM] Savannah, Ga. IEEE.*

Malone, K., Nersessian, N., Newstetter,N. (2005) Gender Writ Small: Gendered Enactments and Gendered Narratives about Lab Organization and Knowledge Transmission in a Bio-Medical Engineering Lab Research Setting. *Journal of Women & Minorities in Science & Engineering.*

Newstetter, W. (2005) Creating cognitive apprenticeships in biomedical engineering. *Journal of Engineering Education.* 94:2.

Newstetter, W. (2006) Fostering Integrative Problem Solving in Biomedical Engineering: The PBL Approach. *Annals of Biomedical Engineering.* 34/2 (217-225)

Fasse, B. B. (2009) An institutional perspective: Problem-based learning in biomedical engineering at Georgia Tech. *International Symposium for Research on PBL in Engineering Education*, Loughborough University, UK, June 2009

Fasse, B. B. (2009*)* Controlling the chaos: Problem-based learning in biomedical engineering at Georgia Tech. *Presented at USG BOR STEM Conference*, Stone Mountain, GA, February 2009

George, S.M., Fasse, B.B., and Lee, K.S. (2010) Acquiring experimental design skills through problem-based learning. *Biomedical Engineering Society*, Austin, TX, October 6-9.

Newstetter, W.C., Behravesh, E, Nersessian, N.J., and Fasse, B.B. (2010). Design principles for problem-driven learning laboratories in biomedical engineering education. *Annals of Biomedical Engineering*, Vol. 38, No. 10, pp. 3257-3267.

Osbeck, L., Nersessian, N.J., Malone, K. & Newstetter, W. (2010) *Science as psychology: Identity and sense-making in science practice.* Cambridge University Press, New York.

Baillie, C., Ko, E., Newstetter, W., & Radcliff, D. F. (2011). Advancing Diverse and Inclusive Engineering Education Practices through Interdisciplinary Research and Scholarship. *Journal of Engineering Education,* 100(1), 6–13.

Litzinger, T. A., Lattuca, L. R., Hadgraft, R. G., & Newstetter, W. C. (2011). Engineering Education and the Development of Expertise. *Journal of Engineering Education, 100*(1), 123–150.

Newstetter, W. & Nersessian, N.J. (2011) Unpacking the interdisciplinary mind: Implications for teaching and learning. *2011 ASEE Conference Proceedings. [CD-ROM]. Washington, DC. American Society for Engineering Education.*

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