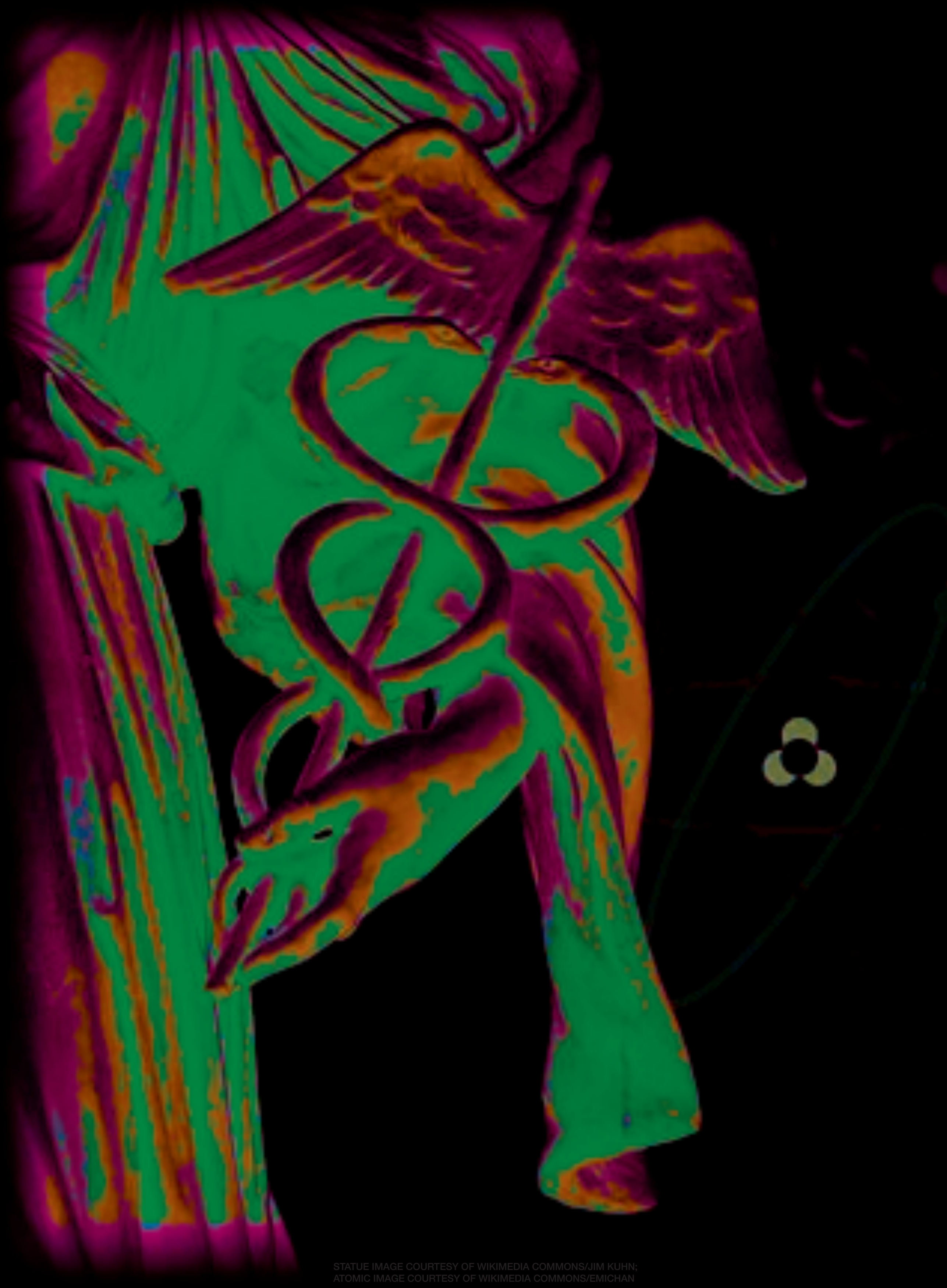

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# Wanted/Found

By Sarah Campbell

## Balancing Needs and Discovery in Biomedical Engineering Education

The ivory tower metaphor for academia's distance from practical society was originally a description, not of a university building, but of a beautiful neck. The phrase, a symbol of noble purity, is traced to the Bible's Song of Solomon. By the 19th century, the phrase pointed to the place that detached dreamers (writers, philosophers, and scientists) holed up to pursue intellectual work. Along the way, the metaphor also gravitated to literal associations with the towers of university campuses (perhaps best epitomized in the two creamy-white towers of All Souls College, the only "pure research college" at Oxford University).

Such delicate towers of pure research are increasingly a figment of institutional memory—the figurative terrain of higher education is no longer dominated by these lofty symbols of intellectual labor, hovering at a remove from the grounded, practical problems of society. "The landscape has changed," observes Phil Weilerstein, executive director of the National Collegiate Inventors and Innovators Alliance (NCIIA). "There's a growing pressure on the university to not just be a source of discoveries in science but also to be a font of innovation to address the needs of society." Broadly speaking, engineering has arguably always been an academic discipline with a foot on the ground, primed to touch down in concrete terms. Nonetheless, a shift in mindset over the recent decades has been necessary to get from the engineer's textbook, laboratory, and notebook to the "needs of society." Biomedical engineering (BME), specifically, is seen by many as especially well suited to meet this challenge, both because of its interdisciplinary nature and because, as a relatively new academic discipline, it has the potential to define itself around this people-oriented focus, without having to slough off decades-old tradition and structures that might be otherwise oriented. The question as to *how* BME is positioning itself to address these needs is perhaps best answered by looking at several predominant trends and efforts in BME education nationally. This article provides an overview of these, which include shaping instruction around a "challenge-based" approach to learning; a move toward approaching problem solving with a global society in mind; increasing entrepreneurial training for BME students; and allowing interdisciplinary work between BME and other fields to be not just an option, but in some programs, a defining characteristic.

### Challenge-Based Instruction

BME programs have undergone tremendous growth in the past few decades, both in terms of sheer proliferation and, where they already existed, increasing their faculty size and caliber of facilities (see "Growth Statistics"). Much of this growth was due to funding from the Whitaker Foundation,

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## Growth Statistics

According to the most recent data from the American Society of Engineering Education (ASEE), BME has experienced a largest growth of any engineering discipline at each degree level over the last decade. Here are some of the growth statistics: Between 2000 and 2009, B.A. degrees granted in BME increased by 215%, M.A. degrees increased by 193%, and Ph.D. degrees increased by 256%.

In 2009, undergraduate BME enrollment was at 19,558 (up from 6,262 in 2000) and Ph.D. BME enrollment was at 5,289 (up from 1,643 in 2000). In 2009, the number of BME-degree granting programs was the following: B.A. degree: 89, M.A. degree: 96, and Ph.D. degree: 81.

*Source:* ASEE data and "Engineering by the Numbers" by Michael T. Gibbons, ASEE.

which was set up to primarily support interdisciplinary medical research with an emphasis on BME. Established in 1975, the Foundation disseminated up to US$700 million in funding, much of it to establish and develop BME education programs and facilities and support of outstanding students and faculty. (Thirty years after establishment, the Whitaker Foundation ceased operations in 2006, announcing that it "felt that it had achieved its primary objective of helping the American BME field grow into a legitimate widespread discipline." The Foundation then committed its remaining funds to an internationally focused grant program for creating links between BME leaders worldwide, the Whitaker International Fellows and Scholars Program [1]).

During the past few decades of skyrocketing growth, there has naturally been a fair amount of conversation around what a bioengineering curriculum should consist of, with several summits on what directions the burgeoning field should take. Prof. Thomas Harris of Vanderbilt University has dedicated the latter portions of his career to this discussion in a variety of roles. Chair of Vanderbilt University's BME department for two decades, Harris was involved in the development of both undergraduate and graduate curriculums and was also the director of Vanderbilt-Northwestern-Texas-Harvard/MIT (VaNTH) Engineering Research Center for Bioengineering Educational Technologies. VaNTH began in 1999 under a nine-year grant from the National Science Foundation and brought together the eponymous collaborating institutions to develop curricula and best practices for teaching bioengineering. Although the grant has since concluded, the effort to continue VaNTH's work continues at various campuses to extend the techniques studied during the span of the grant.

**In a challenged-based approach, students are expected to react to a question.**

Integrating their research with findings from learning science, VaNTH proposes that a "challenge-based" instructional approach, supported by technology, boosts student achievement in bioengineering. In the classical model of university instruction, the teacher leads with a lecture and then poses questions to assist and test students' ability to apply new knowledge. In a challenge-based approach, this model is reordered. The instructor leads with a "challenge"—a question—rather than a lecture, asking students, for example: how should we build an artificial heart? The students are then expected to react to that challenge with their current knowledge—to respond "ahead of time," likely *before* they have all the necessary knowledge. Students' initial response is used as the jump-off point for presenting new subject matter and materials. "You turn things around," explains Harris, "get the students thinking about the application first, then get them involved in the details of how you go about doing that [e.g., building an artificial heart]."

Variations on this challenge-based approach have taken root, not just in BME classrooms around the country, but in programs that BME departments offer to students as part of their curriculum. One such example can be seen in the design of Michigan Technological University's (MTU's) Enterprise Program. The Enterprise Program consists of student teams that are run as if they were a business. The teams are interdisciplinary, with students coming from engineering, business, humanities, sciences, and social sciences, and they work on problems supplied by industry sponsors. Dr. Robert Warrington, director of the Institute for Leadership and Innovation at Michigan Tech, is also a coadviser of the team with a BME focus, the International Business Ventures (IBV) Enterprise (they design biomedical solutions for global markets). Warrington spent many years looking at the academic side of engineering

MTU ENTERPRISE PROGRAM

**FIGURE 1** Michigan Tech IBV team members working on the design for a low-cost ventilator.

education more broadly and at how students learn and how they want to learn. "Certainly we need lecture content," he says, "but over the years [there was] too much lecture content [in education] and not enough being put into creative learning environments." The Enterprises introduce such an environment in part through replicating the challenge-based instruction model described above. Because teams consist of students at all stages of their college careers, they are composed of members with different knowledge bases. In effect, the real-world problems these teams tackle (designing a low-cost ventilator, for instance) are the "challenge," and students must grapple with finding answers they haven't already been given in a classroom lecture (Figure 1). Warrington describes the type of learning that emerges within the Enterprise Program context: "It's interesting, as you watch [the students].... Typically, our second-year students will be working on projects and most of the projects need content well above where they are in the classroom. So the students struggle with problems they really haven't had the background for. So [they are challenged to figure out:] how do they use what they do have? And then [they work] with more senior students to actually ... go learn from others the information." The more advanced students will point the younger students to where they can gather the background they need to complete their parts of the project.

What's more, when the underclassmen eventually encounter the relevant material for a given Enterprise problem in a course, they appreciate its relevance all the more. "Not only do they have to work ahead and learn how to learn," adds Warrington, "but they see the value of the course content when they get it in their senior year." The Enterprise Program, started in 2000, is a signature program for Michigan Tech and distinct from traditional capstone projects in that it spans several years (potentially all four) of a student's enrollment as opposed to just the final year.

Students design products that can have a tangible impact—sometimes on the other side of the world.

Through team endeavors, students help design products that can have a tangible impact—sometimes on the other side of the world. The IBV group has spent several years working on a heart annunciator that can pick up the heartbeat of a newborn infant and announce it by producing an audible beep (Figure 2). This can help clinicians reduce infant deaths, especially in the developing world. A pediatric doctor working in Africa had seen multiple instances in which, because no heartbeat was detected, newborns were believed dead when in fact they were not. The low-cost annunciator can help reduce the incidence of these infant deaths. So far the device has been tested in Ghana, and the IBV Enterprise team will return there this summer to further test its efficacy in the field.

In this way, as students are gaining technical experience in product development for developing-world needs, they are also gaining professional development. Although the Enterprise work is for academic credit only, Director Mary Raber says that students treat it like a job. Perhaps, that's because they are truly exposed to all aspects of running a business, she explains, "from doing the engineering work, to marketing, finance, and recruiting." Students also come away with teamwork and leadership skills and, Warrington hopes, "the background and confidence so that anyone of [them] could start up their own company if they chose."

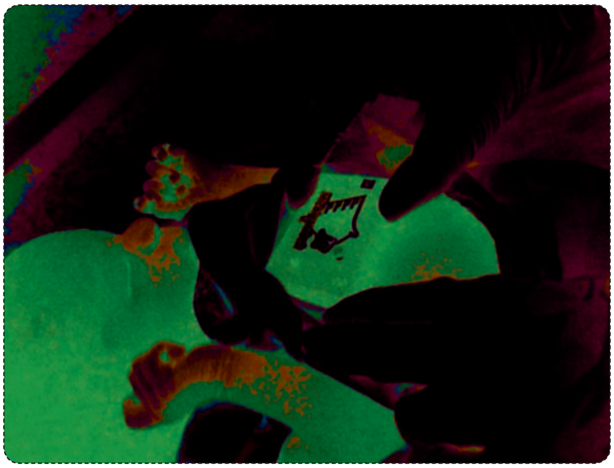
MTU ENTERPRISE PROGRAM

**FIGURE 2** An infant heart annunciator being tested by Michigan Tech IBV students in Ghana, Africa.

## Global Problem Solving

As the work of the Enterprise team on a heart annunciator for Ghanaian medical needs halfway across the world indicates, problems that biomedical engineers are turning to solve are ever more international in scope, and universities recognize the importance of involving students in this problem solving as part of their education. Many universities and granting organizations have designated resources and established groups to design innovative and low-cost technologies that will address health-care needs in developing countries—more than can be comprehensively mentioned here. To highlight just one among the many efforts underway, Northwestern University is home to the Center for Innovation in Global Health Technologies (CIGHT). CIGHT emphasizes studying end users and their environments as an integral step in successfully getting medical technologies to become permanent and realistic solutions in resource-limited settings. Too often in the past, advanced technologies were introduced into poor communities without considering how the cost of operation and maintenance of these devices could be so prohibitive as to mean the failure of these interventions for improved care. At CIGHT, current research efforts include working on an affordable version of digital X-ray technology to reduce the high costs of medical imaging for quick diagnosis of trauma and infectious disease. Additionally, CIGHT also focuses on developing affordable diagnostic platforms for the identification and treatment of HIV/AIDS.

## Engineers as Entrepreneurs

Engineers turning their talents on global—not just local—problems is one bright facet to the changing mindset about

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**FIGURE 3** Case Western Reserve University Prof. Dustin Tyler (center), graduate student Aaron Hadley (left), and physician collaborator Michael Broniatowski, M.D., F.A.C.S. use electrical stimulation of the nerves in the subject's neck to improve swallowing following stroke or other central nervous system disorder, 2009.

what roles engineers play in society. To return to the proverbial ivory tower, you could say that BME is a field in which that tower is becoming ever more grounded, and part of that grounding has consisted of envisioning engineering students as future entrepreneurs.

BME as a discipline is a newcomer compared to other academic divisions, so that may have made it particularly amenable to shaping itself in response to these emerging roles. "It's a relatively young academic discipline, so it's been possible to reframe and integrate (commercialization-oriented) educational opportunities in ways that more established disciplines have been less open to," says Phil Weilerstein.

**When it comes to devices, if it doesn't get commercialized, it's not going to have much impact.**

"Fifteen years ago," says Phil Weilerstein, "the idea of engineers pursuing entrepreneurial projects in the university environment was unusual if not controversial. Now, it's much more embraced but still not widespread." Weilerstein is executive director of the National Collegiate Inventors and Innovators Alliance (NCIIA), an educational nonprofit that supports technology innovation and entrepreneurship in the university sector through a variety of programs and grants. [Around 40% of the faculty and students NCIIA works with are in BME. NCIIA sponsors two competitions, BMEIdea and BMEStart (specifically for undergraduates) to stimulate inventions in medical technologies.] Weilerstein points out that, in some places, it's now the norm for executives at technology companies to have technical backgrounds—they've come up through academic programs and gotten their degrees before embarking on business. But "that was not the case ten to 15 years ago," Weilerstein emphasizes.

Dr. Judy Cezeaux, chair of the BME department at Western New England College, says that of their graduating students these days, "approximately 50% go to graduate school … in any number of different areas, and about 50% go into industry. We want to make sure our program prepares them for that." One such feature, a design history file, prepares students to navigate the Food and Drug Administration (FDA) regulations they will encounter in the medical device or pharmaceutical sectors, and is a component of the senior design projects. The design history file replicates the documentation (the design history of a medical device) necessary for getting FDA approval, establishing that a device meets FDA requirements, specifications, and current good manufacturing practices. Dr. Cezeaux believes that compiling this design history file, one aspect of the type of work involved in commercialization of devices, has helped students land jobs.

Engineers haven't always been good at, or interested in, translational work—getting their designs from bench to bedside, says Dr. Solomon Eisenberg, chair of Boston University's (BU's) BME department, one of the largest and oldest in the country. He adds, "When it comes to devices, if it doesn't get commercialized, it's not going to have much impact." BU is one among the ten Coulter Translational Partnership schools, which means it has funding earmarked for identifying commercialization technologies and facilitates collaboration between BU's Office of Technology Development, the business community, entrepreneurs, and venture capitalists with the goal of moving new technologies more quickly into patient care. "It's not just a matter of making a better mousetrap," explains Eisenberg. "Good ideas die in the laboratory if they can't get connected and supported."

At the same time, educating students in translational work is not only about orienting them to the business roads of commercialization but also teaching them to ask the right questions about a potential product, such as what the product might look like, whether there's a platform for it, and what the use of the technology might be.

At BU, Eisenberg says that the BME department seeks to help students and faculty alike understand "the degree to which there's truly a market need" for a product. "There are a lot of platform technologies that do things that don't need to be done," Eisenberg reveals. "But finding the right application for a platform might make a big difference in getting a sense of need from the medical profession."

## Clinical Immersion

There's no better way to get a sense of need in medicine than by going to the places it is delivered. Several BME education programs offer BME students (from undergraduates to postgraduates) opportunities to observe and work in clinical environments. To varying degrees, participants in these courses and fellowships shadow clinicians, gauge needs, and then design a product using the firsthand knowledge they gained in the clinical context. Some of the schools that offer a range of clinical immersion experiences, from introductory to yearlong, multidisciplinary team endeavors include the following: Virginia Commonwealth University offers its first-year undergraduates an introductory "BME Practicum" that allows students, among other things, to tour medical facilities, clinics, and hospitals and participate in medical seminars, rounds, and workshops. At Stanford University graduate students can take a course, "Clinical Needs and Technology," taught by pediatric cardiologist Dr. Jeff

Feinstein. Laboratories for the course include a pathology/histology session, and each student is paired with a physician to observe an operation or procedure.

At Northwestern University, a popular graduate-level class called *NUvention* brings students from engineering, medicine, law, and business into the hospital to do needs finding followed by brainstorming and prototyping with the aim of inventing biomedical products. Similarly, with a longer time frame to work in, some schools support postgraduate fellowships that do just this kind of need identification paired with in-depth clinical observation followed by product design. The University of Minnesota's Institute for Engineering in Medicine has a four-person cross-disciplinary research team and has invested more than US$4.7 million in more than 90 health engineering research projects over the past six years [2]. At the University of Michigan's Medical Innovation Center, Dr. Laura Walz is a recent BME graduate and current fellow in their program, which also includes three other fellows drawn from different academic backgrounds: engineering, medicine, and business. "The concept is to be a-disciplinary," Walz says, referring to their different backgrounds, "so that by the time we [fellows] come out, we are conversant in all three disciplines."

**Engineers turning their talents on global—not just local—problems is one bright facet to the changing mindset about what roles engineers play in society.**

Walz describes the way her team proceeds: initially, they conduct observations in the clinic. "We pay attention to what's going on and what might not be going right," she explains. "We watch the clinician to see what's frustrating [for him or her], and what takes a long time to do. Then, from the engineer's standpoint, we ask, 'What could we do to make it less frustrating?'" They've learned the importance, notes Walz, of watching not just the procedure itself but everything going on around it. All aspects of the clinical context may offer essential information or clues that would aid in the design of a biomedical device. Since October, Walz's team has been focused on pediatrics, studying and problem solving the high failure rate of emergency paramedics and other clinicians to successfully intubate children. They are now prototyping a device that could facilitate the insertion of the endotrachial tube into patients.

## Degrees of (Inter)Disciplinarity

BME opportunities, such as those described earlier, that are inherently interdisciplinary in their makeup are a reminder that BME is at root an interdisciplinary field. That said, within BME there are nonetheless degrees of disciplinarity. Some programs take a more disciplinary approach while others, such as the jointly run Harvard/Massachusetts Institute of Technology's Health Sciences and Technology (HST) program, put interdisciplinarity and problem solving at the foreground of their curriculum and classroom composition. Dr. Martha Gray has had a variety of roles at HST, from being a graduate of the program herself to overseeing the HST's academic programs. "We tell students, 'You come here because you want to solve problems in medicine. You're in a community of people that want to solve problems in medicine and what area you pick and what disciplines and professions you bring to the table is really up to you.' The hard part," Gray adds, "is figuring out what problem to solve and then figuring out who needs to be involved." Gray says that some students might find this self-navigation and lack of a more clearly delineated path of study challenging. "You don't tell them, 'Take exactly these courses and here are the 20 people you can select from to do your work with.' They have to develop the skill to go figure it out." Gray says HST doesn't claim any particular discipline; instead, the faculty expects each student to develop a deep expertise in something. And if the educational structure looks different at HST, so do the classroom discussions. A doctoral BME student there may take classes with students from a diverse mix of career trajectories, including medical students and business students. "They all share a common goal, which is advancing health, but they come at it from vastly different career aspirations and disciplinary backgrounds. So a classroom in HST is not in any way uniform," Gray explains. This diversity encourages a great deal of questioning—the students question each other, and the faculty, too, take to asking questions. "Faculty will tell you," says Gray, "it's very different. You don't just give a lecture. In HST, you give questions."

## Masters of Many Trades

Giving questions, posing challenges—BME students get ample practice in problem solving as they move through their degree programs, and it's a skill they need not be shy about advertising as they prepare to transition out of academia. "There's a tremendous demand out there for people who are quantitative problem solvers," notes Dr. Solomon Eisenberg. "Biomedical engineers, perhaps more than others, are more interdisciplinary and have marketable skills [beyond] BME which do well by them as they move on

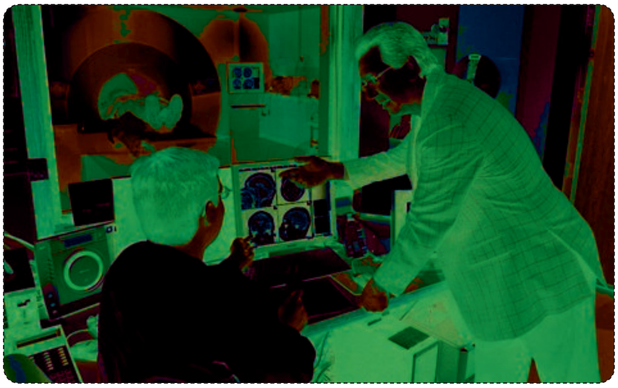

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**FIGURE 4** Case Western Reserve University Professor and BME Department Chair Jeffrey Duerk (right) and Jamal Derakhshan, a student in the Medical Scientist Training Program, examine images from the Siemens research scanner used in the development of rapid magnetic resonance imaging (MRI) methods and new magnetic resonance image-guided interventions, 2009.


BME CAREER ALLIANCE

**FIGURE 5** Participants at a recent BCA career conference held 1 April 2011 at Northwestern University in Evanston, Illinois–Midwest Biomedical Engineering Career Conference (MBECC).

[in their careers.]" Ironically, the very thing that advantageously sets BME apart can also be what makes BME more inscrutable than the older, more recognizable engineering disciplines.

Fortunately for upcoming BMEs, there are organizations whose missions include raising an awareness about the field. One of these, the American Institute of Medical and Biomedical Engineers (AIMBE), is an advocacy group that interacts with congress to raise awareness about the profession in ways that universities, because of their tax code status, are not permitted to. Dr. Jeffrey Duerk, chair and professor of BME (and Radiology) at Case Western University, is also chair of AIMBE's Academic Council. He says that one of the things discussed within the Council and which AIMBE works on "is a misperception by industry that medical and bioengineers are jacks-of-all-trades and masters of none." Duerk speculates that this misperception could be based on BME degrees of the past—40 years ago, say—that were not as rigorous as the ones students work toward today. It's possible, he says, that managers or those hiring are "biased based on what they knew when they were going through college, when the field was in its infancy as opposed to the mature discipline of today." (Figures 3 and 4 highlight student collaborative education experiences at Case Western Reserve University.)

**Fifteen years ago, the idea of engineers pursing entrepreneurial projects in the university environment was unusual if not controversial.**

## Wanted: Biomedical Engineer

Thus, while all signs point to the notion that today, more than a decade ago, BME students exit their undergraduate and graduate programs with a broader panoply of skills to ease their entry into industry jobs, the question lingers: are they therefore more easily getting jobs with their degrees than they did ten years ago? To answer this question, we spoke with Charla Triplett, founder and president of the Biomedical Engineering Career Alliance (BCA), an organization focused on advocating BME degrees to industry (Figure 5). The nonprofit holds career conferences that bring together potential employers and BME job seekers—an equal mix of undergraduate and graduate students at various stages in their degree work—about half of whom are actively seeking jobs. Triplett says that many students emerge from academia focused mainly on getting research and development jobs, not being aware of the other roles they can play in companies—working as clinical engineers or in quality, for example. Her point underscores the fact that an education in BME should include students learning what their range of career options are so that they in turn can help to educate industry in the unique sets of skills that they can bring to companies. "Industry may know of the discipline," says Triplett, "but not necessarily of the skills that come with it."

Prof. Eisenberg at BU agrees that BME graduates have to "work a little harder [to obtain jobs] than [students in] other more traditional disciplines [that are] a 100 years old"—disciplines such as electrical, mechanical, and chemical engineering. Currently, a fair number of BME graduates will take what Eisenberg calls transitional jobs for a year or two before heading to graduate school or obtaining positions in their desired BME career trajectory.

Triplett, meanwhile, has witnessed a shift in industry awareness of the skills that BME can bring to industry. Where companies have traditionally looked to hire basic scientists or chemical engineers, they are now in some sectors realizing that biomedical engineers bring with them a quantitative and problem-solving skill set that basic scientists may not have—or, says Triplett, they may have the "biology knowledge that a chemical engineer might not have." Triplett founded BCA a little more than ten years ago, and in that time frame she has watched as medical device companies came to this realization. Now, they are one of the main recruiters of BMEs. That said, biotech and pharmaceutical companies have roles that would be a good fit for BME graduates, but they need more awareness of that match and "there's still a lot of room for growth," Triplett feels. Still, there has been a palpable shift. When Triplett founded the BCA, she recalls, "It used to be that you would never see the words 'biomedical engineer' in a job description anywhere. I would have to explain over and over again what BME was … and that is not the same today and that is exciting."

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