The Need for Effective Biomedical Imaging Education

Challenges of and Resources for Education to Meet the Growing Demand for Trained Biomedical Imaging Engineers

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Biomedical imaging (BMI) is a strong and growing subdiscipline of biomedical engineering (BME), with applications in basic science research, medical diagnosis, and the guidance of therapeutic interventions. Of 112 academic programs in BME profiled on the Whitaker Foundation Web site [1], at least 67 involve imaging. The field of BMI is so important that, just two years ago, the National Institutes of Health broke from its traditional disease and organ institute model and created the National Institute for Biomedical Imaging and Bioengineering (NIBIB) to support research in this area. The recent Radiological Society of North America meeting (December 2002) included on the order of 2,600 papers with up to 30 parallel sessions, posters, specialized educational presentations, and 300 or more commercial exhibits. While this is largely a medical meeting, it is based on imaging technologies developed and supported by biomedical engineers and others from related disciplines. The U.S. Department of Labor predicts a 31.4% increase in jobs in BME and a 23.1% increase in jobs for radiologic technologists and technicians between 2000 and 2010 [2]. Since BMI is a subdiscipline of BME and a field closely related to the work of radiologic technologists, these employment statistics can be used to infer a strong need for a continued supply of engineers well trained in the field of BMI.

The number and complexity of BMI modalities have increased dramatically over time. While X-ray radiography is over a century old, the last few decades have brought about tremendous innovation in the field with magnetic resonance imaging (see Figure 1) [3], helical multislice computed tomography [4], electron beam computed tomography [4], positron emission tomography (see Figure 2) [5], and three-dimensional (3-D) ultrasound imaging (see Figure 3) [6], just to name a few. These rapid developments require not only a well-prepared BMI workforce but also require rapidly adapting educational programs.

Both radiologists and the persons who create the images radiologists interpret—radiologic technologists, ultrasonographers, nuclear medicine technologists, and MRI technologists—have had long-standing requirements to obtain and maintain certification of their competency in their respective fields. Basic scientists and engineers in the field of imaging must also obtain certification of competency if they wish to have the authority to attest to the satisfactory performance of medical imaging equipment. Attainment and maintenance of these certifications provide another impetus for BMI education, especially of the kinds that are convenient and effective for the working professional.

Evolving BMI Education

Not long ago, nonclinical professionals working in the field of medical imaging—developing and investigating new imaging technologies and performing quality assurance and accep-

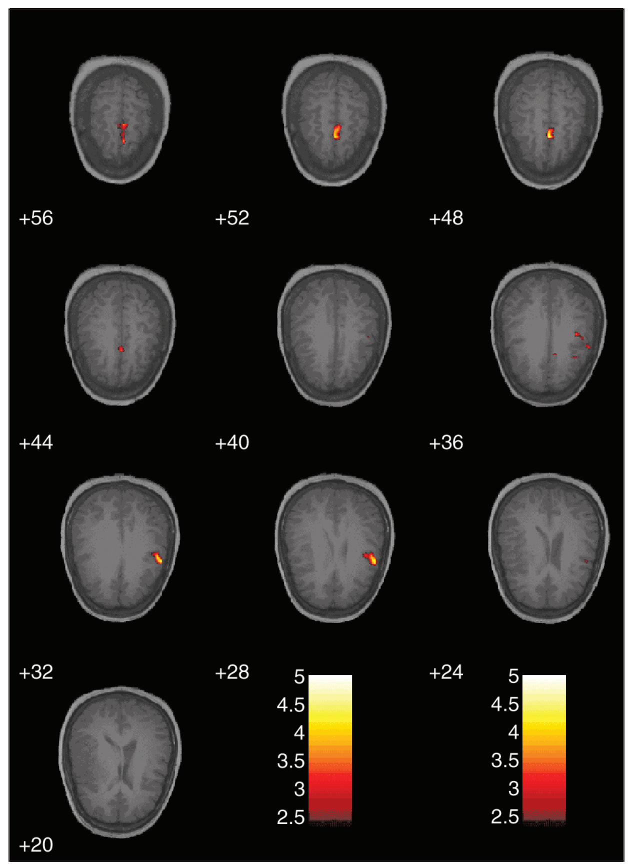

Fig. 1. Axial magnetic resonance images with functional MRI data overlaid in color that demonstrate the ability of MRI to localize and measure brain function. The colored regions indicate brain areas used to generate words that begin with a letter presented to the subject.

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tance testing—were all physicists with degrees in physics followed by on-the-job training in medical imaging. Undergraduate degrees in physics and graduate degrees in medical physics became the next path to obtaining credentials. Now, undergraduate and graduate education in BME has become a well-accepted and common path to obtaining the necessary background to work in the field of BMI. While study in physics remains a viable path, a BME education offers the advantage of integrating physics, engineering methods and technology, and biomedical training.

The Challenges of BMI Education

There are several challenges to producing high-quality BMI education programs. These include limited opportunities for hands-on education; a dearth of textbooks targeted toward engineers, especially undergraduate engineers; and, like many fields, advancements so rapid that textbooks and other educational resources become out of date quickly, often before being released.

The use of actual BMI equipment for education, while desirable for real-life hands-on learning, is often not feasible due to safety concerns, high cost, and lack of availability. It is possible to purchase, for laboratory use, small X-ray tubes and radiolabeled compounds similar to those used for X-ray-based or radionuclide imaging techniques, respectively. However, exposure to such sources of ionizing radiation is associated with a number of safety risks, including serious skin burns [7] and increased cancer risks [8].

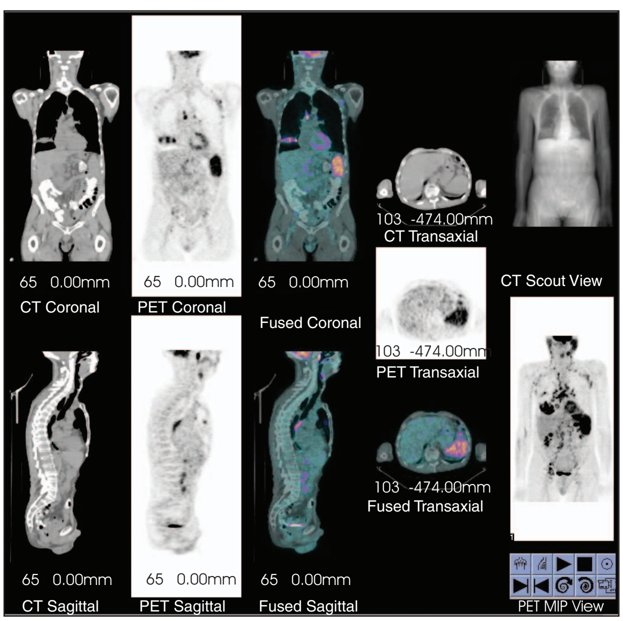

Fig. 2. Computed tomography (CT) and positron emission tomography (PET) images of a patient with lymphoma in coronal, axial, and sagittal planes shown separately and fused together.

Safety risks aside, the cost of BMI equipment prohibits its purchase solely for hands-on education with small X-ray tubes without detection systems starting at about US$2,000, complete ultrasound systems running US$80K to US$200K, and MRI units on the order of US$1 million or more. These equipment costs, coupled with siting costs, are far greater than nearly any educational program can afford.

While BMI equipment abounds in the radiology departments of any major medical center and even in free-standing imaging clinics, the availability of such equipment for learning purposes is extremely limited due to the requisite priority patient examinations have for the machines. Also, while many undergraduate BME programs are housed very near a major medical center, some do not have convenient access to imaging equipment.

There are a great many textbooks available in the field of medical imaging. However, most of these are targeted toward a clinical audience—radiologists prescribing imaging studies and interpreting their results and technologists performing the studies. Understandably, these books typically do not include much of the engineering and physics of imaging. Those that do are often targeted toward a graduate-level audience, leaving undergraduates studying BMI with limited textbook resources.

Resources for BMI Education

Although there are many challenges to BMI education, there are many resources available that support its success. Many of these resources are Web based, including textbooks [9], [10], tutorials, simulators, and teaching files. One online tutorial for ultrasound was shown to be as effective and more efficient than lectures [11] in helping BME students learn the basics of ultrasound.

Radiology teaching files are a widespread, traditional tool for radiology resident education. These teaching files include some patient information and associated medical images. The learner is directed to make a diagnosis and in some cases asked to prescribe the best follow-up imaging procedures. Many institutions have now placed their radiology teaching files and related educational resources online ([12]-[15] and others) with free access available to anyone for asynchronous learning. While the typical biomedical engineer may not be interested in learning medical diagnostic skills, he or she ben-

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Fig. 3. 3-D ultrasound image of a fetal face and hand.

efits greatly from ready access to so many examples of images from different modalities and for different applications. Viewing such images gives BMI students better understanding of the modality and better appreciation for the engineering and science required to produce the images.

The Web sites of medical imaging equipment manufacturers are another source for images, pictures of hardware, and information about applications [16]-[18]. These Web sites sometimes also include tutorials, although access to the tutorials may be limited to current customers. The competitive nature and financial resources of industry lead to the production of high-quality Web sites with frequent updating of the content. Thus, these Web sites offer the BMI student access to state-of-the-art images and potentially many other learning resources.

Given the difficulties of trying to use real imaging equipment for education, simulators can be useful as adjuncts to classroom learning. Some computer-based simulators are available online [19]-[21], and more realistic (and more expensive) hands-on simulators are also available for purchase (e.g., the UltraSim® simulator by MedSim USA, Inc., Ft. Lauderdale, Florida [22]). The effectiveness of any simulator depends on how closely it mimics real life in operation and in display of realistic images. With the large number of variables involved in any BMI task—from physiologic variations to physical principles of energy-tissue interactions to discrete sampling and computational issues—simulators of necessity rely on a great number of simplifications. These simplifications facilitate development and use of simulators but also limit their realism and thus limit their effectiveness for learning.

Another resource for BMI learners is the use of models to help learn the principles of imaging. These models can provide very inexpensive alternatives for hands-on learning. For example, a water wave tank such as is often used in high school physics classes can be used to teach ultrasound principles. Visible light can be used to teach principles of X-ray imaging including attenuation as a function of thickness, magnification, and penumbra [23].

Taxonomy

Logical organization of imaging knowledge can be another learning resource by drawing out the parallels and hierarchy of concepts. There is, however, more than one logical organization of imaging knowledge. The table of contents of a BMI book often provides a good starting point for a BMI taxonomy. The more clinically oriented textbooks often organize BMI knowledge along organ system and disease categories such as “neuroradiology,” “musculoskeletal radiology,” or “imaging of coronary artery disease.” For biomedical engineers, a more logical taxonomic organization applicable to all imaging modalities might follow this form: energy source, interactions of that energy with tissue, detection of that interaction and image formation, applications and techniques (including hardware and safety issues), and image features. A taxonomy organized along these lines is available online [24]. In brief, it begins with global concepts common to all modalities such as signal-to-noise ratio, anatomic and imaging planes, and dimensions, and follows with sections on X-ray-based methods including radiography, fluoroscopy, and computed tomography; radionuclide methods; ultrasound; and magnetic resonance imaging. Within each of these last four sections, the nature and production of the energy type (e.g., X rays, gamma rays, and positrons, sound waves, and radiowaves) is outlined, and then the interactions of that energy with tissues are discussed. Finally under the hierarchy of each energy type, the detection of energy-tissue interactions and image formation, applications and techniques, and image features are detailed, as noted above, for more specific imaging modalities.

Challenge-Based Learning

Research on human learning and its implications for instruction, detailed in a National Research Council report called *How People Learn* [25], indicates that instruction designed around “anchored inquiry” of interesting challenges [26], [27] is particularly effective. Students’ inquiry processes can be guided by an instructional sequence around a learning cycle called the “legacy cycle” [27]. The learning cycle begins with a strongly contextually based challenge. The challenge statement provides enough background information to access students’ intuitions and build interest. Careful selection of this challenge is critical to motivating the desired student populations. Such an approach is in many ways the basis of radiology teaching files in which the challenge is to make the correct diagnosis based on clinical and image information provided. Analogous challenges are needed to facilitate effective instruction of engineers learning BMI principles. This contextual learning provides opportunities for students to notice how fundamental principles of BMI apply to various conditions, which ultimately lead to their ability to use this knowledge in the future. Sample challenges for engineers in BMI might include determining the source of an image artifact (relevant to image formation, hardware, and basic principles); identifying the physical properties of a tissue or object appearing in an image; or using images to accurately guide intervention, with students motivated in all cases by the desire to contribute to improved patient outcomes.

Looking Toward the Future

The trends indicate that demand for persons trained in BMI is increasing and can be expected to continue to increase in the foreseeable future. With increased demand for personnel and growing complexity of the field, the need for effective and efficient educational techniques will become more and more important. Online educational resources, allowing anytime/anywhere learning with the potential for educational interaction, will continue to grow in importance for BMI education. However, without a clear revenue model and with the volatility of the medium, it is uncertain that such online educational resources will ever attain the stature, prevalence, and continued utility of printed textbooks. Whatever the medium, hands-on learning exercises, simulators, and challenge-based learning should be included wherever possible to improve the effectiveness of BMI education.

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