*Suggestions for topics suitable for these Point/Counterpoint debates should be addressed to the Moderator: William R. Hendee, Medical College of Wisconsin, Milwaukee: whendee@mcw.edu. Persons participating in Point/Counterpoint discussions are selected for their knowledge and communicative skill. Their positions for or against a proposition may or may not reflect their personal opinions or the positions of their employers.*

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# Educational programs for imaging physicists should emphasize the science of imaging rather than the technology of imaging

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## OVERVIEW

Some imaging physics educational programs focus on the cross-cutting principles of imaging, with specific technologies presented as applications of these principles. Proponents of this approach believe that it provides a solid foundation for trainees to work in any imaging field. Other educational programs emphasize knowledge of specific imaging technologies and their applications in the clinical setting. Advocates of this pathway feel that imaging physicists invariably confine their practice efforts to a specific technology (e.g., x ray and CT, medical, nuclear, ultrasound or MRI), and their educational experience should support this concentration of effort. This controversy is the subject of this month's Point/Counterpoint.

Arguing for the Proposition is Paul M. DeLuca, Ph.D. Dr. DeLuca received a Ph.D. in nuclear physics from the University of Notre Dame, and immediately joined the University of Wisconsin as a Research Associate. Presently Dr. DeLuca is Professor of Medical Physics, Radiology, Human Oncology, Physics and Engineering Physics. He served as Chair of Medical Physics from 1987 to 1998. In 1999 he assumed a role in the Medical School as Associate Dean for Research and Graduate Studies, and his administrative role was expanded in 2001 with an appointment as Vice Dean. His research interests have concentrated on fast neutron production and dosimetry, determination of elemental neutron kerma factors, and application of microdosimetry to radiation dosimetry. He currently is Vice Chairman of the International Commission on Radiation Units and Measurements (ICRU). From 1999–2003 he served as a Chair of the Nonproliferation and International Security (NIS) Division Review Committee (DRC) at Los Alamos National Laboratory (LANL) and currently is a member of the LANL Threat Reduction (TR) Directorate Program Review Committee (PRC).

Arguing against the Proposition is Mitchell Goodsitt, Ph.D. Dr. Goodsitt received his M.S. in radiological sciences and Ph.D. in medical physics from the University of Wisconsin, Madison. After graduating in 1982, he became an Instructor of Radiology/Assistant in Physics at Harvard Medical School/Massachusetts General Hospital. From 1986–1992, he was an Assistant/Associate Professor at the University of Washington. In 1992, he moved to the University of Michigan, where he is presently Professor of Radiological Sciences. His primary areas of research are quantitative CT, mammography, and ultrasound. He presently directs a course on the physics of diagnostic radiology for residents and graduate students, guest lectures in the nuclear engineering department, and co-teaches an x-ray physics/CR lab for a biomedical engineering course. He is certified in diagnostic radiologic physics by the ABR and was recently elected a fellow of the AAPM.

## FOR THE PROPOSITION: Paul DeLuca, Ph.D.

### Opening Statement

As a confirmed experimentalist, my first instinct is to change places with Dr. Goodsitt! In any case, the previous 40 years of unimagined creativity in imaging science, demands an examination of the field of medical image science. Following the 1895 discovery by Roentgen, transmission radiography and fluoroscopy, fully conceptualized and partially developed by 1896, rapidly reached a mature state of affairs. The next 70 years showed modest advances in image receptors, source design, HV generators, and other aspects of image acquisition. New medical imaging modalities developed slowly in a methodical manner, including ultrasound and radionuclide-based imaging. By the early 1970s, however, one could sense an impending revolution.

Computer processor speeds increased at a prodigious rate, transistor gate densities increased exponentially, and processing power put early Cray-level computing power on desktops. Computed tomography started the onslaught of modern volume-image science. Magnetic resonance imaging devices added enormous capability to volume imaging and complemented CT imaging. Changes after 1980 were dramatic. High performance electronics, smart control systems, and enormous advances in large-area, fully-digital image receptors led to a broad range of imaging devices with ever more elegant capabilities to provide very high resolution, 4D image acquisition with highly adaptable acquisition strategies. Finally, modalities started to fuse to permit concurrent acquisition of physiological and anatomical information—the determination of function.

How then shall we prepare scientists (i.e., medical physicists), to work and perform research in this developing area? Traditionally, image science curricula were founded in the modalities, the physics of image acquisition. They usually commenced with so-called diagnostic imaging (transmission radiography), nuclear medicine imaging (often not including PET), ultrasonic imaging, thence volume imaging (CT and PET), and perhaps aspects of specialized digital imaging (e.g., DSA). While satisfactory 30 years ago, this curriculum fails to capture the underlying common image formation concepts and mathematics. The principles of image formation are quite general and apply to all modalities. In fact, the underlying mathematics (the inverse problem), is widely applicable across volume imaging. This was first recognized by an early publication of the ICRU,[1] and more recently in the outstanding text by Barrett and Myers[2] (2004). Casual reading of the latter's table of contents emphasizes the broad nature of the math and statistics of image formation. With this foundation, a curriculum built on these overarching principles can with confidence proceed to a discussion that builds on determining the underlying biological functionality, while including the prerequisite anatomical information in the broad context of the underlying math and physics. Modality-based discussion is presented in the context of the interrelation amongst modalities and their concomitant ability to determine function. This is precisely the direction of the recent recommendation of the AAPM guidance documentation.[3]

### Rebuttal

As expected, Dr. Goodsitt and I are actually rather close in our thinking as well as our shared concerns about learning, namely can instruction and learning realistically be bifurcated into theory and practice without compromising understanding. It truly is a matter of degree!

However, this conundrum is more or less exactly the situation encountered in undergraduate physics or engineering. Quite often introductory physics courses, even for physics majors, are taught without a solid foundation in calculus, differential equations or special functions. These courses often include electricity and magnetism or classical mechanics. In these situations, and as correctly noted by Goodsitt, in some manner or other the underlying math is taught concurrently with the physics! Time and time again, this process has resulted in less than adequate preparation for graduate level physics—perhaps adequate for a B.S. degree, but deficient for Ph.D. level courses. In comparison, when calculus through differential (or partial differential if possible), special functions, and linear algebra are well understood, mechanics and electromagnetic fields take on the beauty and symmetry that truly makes them forever understood. Coming from the former process, I still struggle with even modestly complex electromagnetic field theory having first learned E&M without the needed mathematics.

Even so, the contrary view, defended by Goodsitt, has clear merit when the understanding of the imaging process is very tightly coupled to the modality under study. In fact accepting that viewpoint leads exactly to the problem. Namely, students, after a year or so of modality-based instruction, are now challenged to understand the broad common footings that underpin all modalities. Frustration sets in, or even worse the student never clearly grasps the common underlying elements of the image formation process. Image processing in astrophysics or space science starts from the first principal approach for exactly this reason. Goodsitt makes exactly this point when he states "When students start out in a medical physics program, many have not yet decided which modality or modalities to specialize in … this can change later in their careers … research in multimodality and multiscale imaging has a promising future. Thus, it is beneficial for the students to learn the fundamentals of each imaging modality to a substantial depth, because they may eventually use those modalities in their research." These remarks embody the compelling need for a common underpinning in training and on this point we agree!

## AGAINST THE PROPOSITION: Mitchell Goodsitt, Ph.D.

### Opening Statement

I do not think this is an either/or proposition. Rather, I believe that to produce well-rounded imaging physicists, the education curriculum should emphasize both the technology and the science of medical imaging. The debate, as I interpret it, is more a choice of which to emphasize first, the physics and technology or the generalized mathematics of medical imaging. I believe it would be a great disservice to the majority of imaging physics students if the education programs first emphasized the generalized mathematics and cross-cutting principles of imaging (e.g., impulse response functions) at the expense of the physics and technology. I base this opinion on my experiences as a student, teacher, and researcher. There is a great diversity of skills and backgrounds of students who enroll in medical physics educational programs (e.g., students with undergraduate majors in physics, biophysics, bioengineering, biology, computer science, mathematics, etc.) Having a curriculum that starts with courses on the physics and technology of each major modality would benefit the majority of these students. First and foremost, it teaches the students the fundamentals of each modality to a sufficient depth that the students can better appreciate the meanings of the equations they will learn in imaging mathematics courses. Second, in many cases the physics courses provide students with introductory and conceptual treatments of imaging topics such as Poisson statistics, the sampling theorem, convolutions, Fourier transforms, etc. that many of the students will need to better comprehend the far more in-depth treatments of such topics in imaging mathematics courses. When I was a student at the University of Wisconsin, our curriculum followed this approach, and it worked very well. Since then, in my teaching experience, I have observed the results of the opposite ordering of courses, wherein students first take a class devoted to generalized mathematics of imaging science. These courses typically involve very brief introductions to topics followed by derivations of fairly complex mathematical equations related to the topics. For example in Macovski's excellent *Medical Imaging Systems* textbook,[4] which is employed in many of these courses, $3\frac{1}{2}$ pages are devoted to deriving the generalized transmission equation for a parallel grid:

$$T(\theta) = \left\{ \frac{1}{s}[(n+1)s - h\tan\theta]e^{-n\mu t/\sin\theta} + (h\tan\theta - ns)e^{-(n+1)\mu t/\sin\theta} \right\},$$

$$\tan^{-1}\left(\frac{ns}{h}\right) < \theta < \tan^{-1}\left[\frac{(n+1)s}{h}\right],$$

where $T(\theta)$ is the transmission at angle $\theta$ relative to the normal, $n$ is an integer that takes on values between 0 and infinity, $t$ is the thickness, $h$ is the height, $\mu$ is the linear attenuation coefficient, and $s$ is the period $(=1/\text{frequency})$ of the grid strips.

All of us can appreciate the elegance of this equation and other equations that appear in this text. The problem I have witnessed is that the students and instructors frequently concentrate on the mathematics of imaging science to the detriment of basic principles such as knowing the purpose of grids and their effects on image quality and patient dose. Such concepts are best taught first in a less mathematically rigorous course devoted to the physics and technology of x-ray imaging.

When students start out in a medical physics program, many have not yet decided which modality or modalities to specialize in. Even after they've decided on a specialty, this can change later in their careers. Furthermore, as described at the 2003 Biomedical Imaging Research Opportunities Workshop,[5] research in multimodality and multiscale imaging has a promising future. Thus, it is beneficial for the students to learn the fundamentals of each imaging modality to a substantial depth, because they may eventually use those modalities in their research. Once this is accomplished it is logical to progress to the generalized mathematics of medical imaging courses, where as stated by Macovski in the preface to his textbook, "a formal mathematical structure is provided, which should prove useful for the reader interested in further more detailed analysis."

## Rebuttal

I hate to be the old fogey here, but what worked in medical physics education 30 years ago can still work very well today. It just has to be updated to include new technology (e.g., DR, multidetector helical CT, MRI, PET, image fusion, etc.) The AAPM Report[3] that Dean DeLuca cites doesn't disagree with my thesis — it recommends for image science, "modality-driven material as well as overall materials such as the inverse problem, signal processing, etc." The AAPM report promotes freedom in curriculum design such as combining and redistributing topics, but the core curriculum that is outlined is basically the same as it was 30 years ago with the updates mentioned above. The new textbook *Foundations of Image Science* by Barrett and Meyers[2] that is recommended by Dean Deluca does appear to be outstanding. It contains over 1500 pages of text, with probably about as many equations, covering topics such as linear vector spaces, eigenanalysis, singular-value decomposition, pseudoinverses and linear equations, etc. I still fear that students using this as their first textbook in medical imaging will be overwhelmed by the complex mathematics and lose sight of the general principles. While there may be a few exceptional students who would do fine, the majority would be better off the old way, starting with the basic imaging physics for each modality and ending with unified imaging theory and mathematics.

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[1] International Commission on Radiation Units and Measurements, "*Medical Imaging–The Assessment of Image Quality*," ICRU Report 54, International Commission on Radiation Units and Measurements, Bethesda, MD, 1995.

[2] H. H. Barrett and K. J. Myers, *Foundations of Image Science* (John Wiley and Sons, Hoboken, NJ, 2004).

[3] AAPM Report 79, *Academic Program Recommendations for Graduate Degrees in Medical Physics* (Revision of AAPM Report No. 44) (American Association of Physicists in Medicine, Maryland, 2003).

[4] A. Macovski, *Medical Imaging Systems* (Prentice-Hall, Inc., Edgewood Cliffs, NJ, 1983).

[5] P. L. Carson *et al.*, "Biomedical imaging research opportunities workshop: Report and recommendations," Radiology **229**, 328–339 (2003).