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A Paradigm for the Integration of Biology in Materials Science and Engineering

By Ryan K. Roeder

Posted on: 8/5/2010 12:00:00 AM... *Recent advances in biological and biomedical materials are explored as a technical topic in the July 2010 issue of* JOM. *A rapidly expanding field, pushed in large part by the demands of an aging population that expects to remain healthy and active, the development and study of biomaterials, biological materials, and biomimetic materials present a rather complicated set of challenges stemming from the lack of a common framework for critical thinking and a common language between disparate disciplines. In his paper, "A Paradigm for the Integration of Biology in Materials Science and Engineering," Ryan K. Roeder, an associate professor at the University of Notre Dame, addresses this issue by modifying the materials science and engineering paradigm to account for the adaptive and hierarchical nature of biological materials. The following is an excerpt from that paper.*

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Article Excerpt
Most materials scientists and engineers recognize the tremendous opportunities available at this time in history for advances in biotechnology or biomedicine and, closer to home, the intersection of materials and biology. Materials science and engineering is expected to play a highly significant role in the foreseeable future of biomedicine.[1,2] Conversely, noting that materials science finds its roots in solid state physics and chemistry, biology is logically the next great frontier for materials science and engineering.[2–4] However, researchers and educators working to integrate biology or biomedicine into materials science and engineering, and vice versa, have invariably encountered several challenges. These challenges may be grouped into two aspects of "biocomplexity."

First, biomaterials replace or interface with biological substances, especially tissues and cells. Biological tissues, or biological materials, are living, adapt to chemical and physical stimuli, perform multiple functions, and exhibit hierarchical structure with precise organization over multiple length scales.[5] Therefore, biological materials exhibit complex processing-structure-property relationships, unmatched in engineering materials, which are only beginning to be established.

In contrast, the vast majority of biomaterials used in biomedical devices have historically included common engineering materials (e.g., stainless steel, titanium, alumina, porcelain, polyethylene, polymethylmethacrylate, etc.) that exhibited desirable properties that were borrowed for biomedical applications.[1,6] These biomaterials enhanced the quality of life for countless individuals through passive interaction with biological systems (bioinert). In other words, "do no harm."[7] Thus, metallurgical or materials engineers were well-positioned to contribute to the design and manufacturing of a conventional stainless steel implant, for example, through traditional education in physical metallurgy or materials structure-property relationships, with little consideration of biology.

A second generation of biomaterials began to introduce materials that are favorably reactive to biology, including bioactive ceramics and glasses (e.g., hydroxyapatite and bioglass, respectively) and biodegradable polymers (e.g., polylactide and polyglycolide).[6,7] In the present age, so-called third generation biomaterials are intended for proactive interaction with biology.[6,7] Examples include: tissue engineering scaffolds able to guide cell differentiation and tissue growth via signal transduction;[7–9] vehicles for controlled and/or targeted delivery of pharmaceuticals, proteins, and nucleic acids;[10,11] and multifunctional diagnostics and sensors;[11–13] among others. Materials scientists and engineers who wish to contribute to these and other exciting applications of biomaterials must become increasingly knowledgeable, or at least conversant, in biology and biomedicine.[2,3] Second, biomaterials research and development requires diversity among contributors and collaborators. For reasons discussed above, no single individual or discipline of study can be expected to possess sufficient depth in the full breadth of knowledge required for most biomaterials applications. Thus, product development teams in industry and (increasingly) collaborators in use-inspired basic research in academia may include individuals educated in engineering (chemical, materials, mechanical, etc.), science (cell biology, biochemistry, etc.), basic medical sciences (anatomy, pathology, pharmacology, etc.), and clinical medicine (cardiology, orthopedics, radiology, etc.). The diversity of thought contributed by each field of expertise is recognized as a great benefit in interdisciplinary work. However, a significant challenge facing bioengineering as a discipline, as well as the integration of biology in traditional disciplines, including materials science and engineering, is the lack of a common framework and common language for synthesizing the diversity of thought and expertise.[3]

LESSONS FROM OUR PAST
The history of materials science and engineering provides valuable lessons that can be applied to the present challenge of integrating biology in materials science and

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engineering. Modern materials science and engineering resulted from the integration of traditionally disparate disciplines that were delineated by classes of materials, viz., metals, ceramics, and polymers. As early as the 1950s, materials education was nascent, but critics suggested that the breadth of a materials curriculum without traditional demarcations between material classes would compromise depth of study.[18] Proponents of materials-generic education, such as Gerald L. Liedl, recognized the opportunities and challenges:

"The diversity in the field is, on one hand, a major asset in addressing problems, but on the other hand, a major obstacle in unifying an educational approach. This problem is not new since we have faced it over time as information and knowledge expands."[19]

Despite the pre-existing traditions and human nature to resist change, materials science and engineering has evolved over the last fifty years into a unified discipline of study with an identifiable, common core curriculum.[20–23] The integration of metallurgy, ceramics, and polymers into materials science and engineering was facilitated in large part by a unifying paradigm based upon the underlying principles of processing, structure, properties, and performance, and their interrelationships, that is now well accepted.

Interestingly, the reservations once raised against materials education have been similarly raised against bioengineering education, as well as the integration of biology in traditional disciplines, including materials science and engineering. Considering the history of materials science and engineering, a common paradigm might also help to unify the differing backgrounds, perspectives, and terminology of those who find themselves at the intersection of materials and biology. The objective of this paper is to introduce possible modifications of the materials science and engineering paradigm for the integration of biology. Conversely, the modified paradigm may also be used for the application of materials science and engineering principles to the study of biomaterials, biological materials, and biomimetic materials.

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