INTEGRATING THE TRADITIONALLY TRAINED MECHANICAL ENGINEER (PROBLEM-SOLVER) INTO MODERN MEDICAL RESEARCH PROJECTS

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Abstract — *The fast pace at which medical research is presently advancing, due in large part to recent discoveries in molecular biology, provides exceptional opportunities for crossover research careers for mechanical engineers whose expertise is needed in this area. "Innovation" is the desired outcome of the fusion of the technical expertise of engineers with the human-health orientation of contemporary medical research projects. The disparate cultures of those two endeavors do, however, provide impediments to the successful transitioning of mechanical engineers. Thus, both sides need to become proactive, since various aspects of the cultures of engineering and medical research disciplines act passively to inhibit integration. For mechanical engineers to gain traction in the field of medical research, understanding those cultural differences represents the first step towards devising optimal strategies for adaptation.*

INTRODUCTION

With the rapid advancement of research in basic biology and related biomedical fields, these decades are often referred to as the "golden age of biology." Not since Charles Darwin's publication of the Origin of the Species has the discipline of biology experienced such a profound effect on so many aspects of world cultures, personal belief systems, and human expectations. Discoveries associated with genome (DNA) sequencing, regulation of gene expression, human disease-causing agents (e.g., HIV), genetic engineering of agricultural animals, embryonic stem cells, drug development and vaccine production are propelling an unprecedented, almost tsunami-like, wave of interest and effort in biomedical research/human health related endeavors.

The excitement surrounding those ventures has of course enhanced our expectations for the positive impact biomedical research will have on the path of human history. Indeed, as a national (USA) priority, there has been an increased emphasis on so-called "translational research". The National Institutes of Health (NIH) has, for example, been attempting to generate interest in this type of research [1]. The concept is straightforward: Basic research findings stimulate clinicians to develop novel patient-oriented strategies for coping with health issues. Its practice is, however, a different matter. The substantial "academic/training" gap between the laboratory scientist and the clinician, coupled with the enormous legal (i.e., regulatory), financial, and logistical complexity of conducting relevant patient-based studies are proving, in many instances (e.g., testing medical stents for aiding aneurysm patients) to be difficult.

Furthermore, the complexity of the information content that is a prerequisite for effective translational research is ever increasing. Thus, interdisciplinary approaches that provide connections and bridges among sub disciplines (e.g., between bone molecular biology and mechanical engineering) likely will generate enhanced research productivity. Especially, since mechanical engineers usually think in problem-solving terms, translational research stands to gain from their participation in a wide variety of projects. But with research activity conducted at an always increasing, in many instances, almost feverish pace, and information transfer so rapid, the competition for the novel ideas that underpin the funding for individual laboratories has placed a premium on "innovation". This circumstance favors the "transitional" scientist, such as the traditionally trained mechanical engineer who seeks a career in biomedical research [2].

CULTURAL CONFLICTS EXIST

Innovation is the goal of the fusion of engineering and biomedical research endeavors

Innovation is simply defined as "introducing something truly new." Its sources are, however, certainly much more complex

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than its definition, and not easily identified. Literally, hundreds of research studies have led to inconclusive, inconsistent and usually low levels of explanation (e.g., see [3]). Nevertheless, attempts at defining the casual variables associated with innovation continue. Among the various factors which show up on many "innovation strategy lists" include: Consideration for the individual's work environment preference (fast-paced, or structured, or relaxed, etc.); willingness for supervisors to entertain "high-risk" approaches; refraining from focusing on "reasons/probability for failure," sharing of information; unrestricted research boundaries; enhanced intra-group communication; organizational culture which formally rewards creativity; etc. Needless to say, to promote innovation as many of those factors as possible should be incorporated. No single one will suffice.

For "fusion enterprises" in science one common denominator often is, however, the movement of individual specialists into a new field. It is this feature that, for medical research, involves the integration of techniques, ideas and methods gleaned from the "newcomer" that often propels efforts by medical researchers to recruit engineers to ongoing projects. Non overlaps in core expertise likely will provide the greatest gains over the long term (see [4]). In order to achieve that main benefit from engineering/biomedical research collaborations, it is necessary, however, to establish a "culture of innovation" in individual laboratories. Working against concerted efforts at developing such a culture of innovation is the fact that the NIH funding process increasingly favors "conservative" projects, due in part to the fact that the grantees who serve on the review panels are aging. Proven technologies, preliminary data, and "proof of principle" are common prerequisite features for a successful grant application (reviewed in [5]). Thus, a proactive approach will be required in order to achieve the full potential from fusion enterprises such as those that involve mechanical engineers and medical researchers.

Complementary skill sets (with some overlapping) provide a starting point for transitioning engineers to biomedical research

Anecdotal observations reveal that substantial numbers of mechanical engineering students elect that career path rather than careers in the life sciences because they do not like to either read or write extensively in this field, but rather solve problems. The stage is set, therefore, for a potential cultural conflict from the very beginning of those disparate career paths, since the written report, grant application, and monograph are widely regarded as benchmarks for career success in biomedicine. However, with life science disciplines often acknowledged to represent a new paradigm for engineering careers, and with magnitudes more research funding available for medical research (compared to traditional mechanical engineering extramural research grant funding) the draw of biomedical research continues--unabated--to magnify (e.g., [6]).

Figure 1 illustrates several of the skill sets that usually dominate in the "problem-solving" engineering and "hypothesis-driven" contemporary biomedical research disciplines. A clear distinction between their emphases is readily apparent. Merging those skill sets in such a fashion that they are fully available to a single, specific research project is of course expected to provide a gateway to innovation.

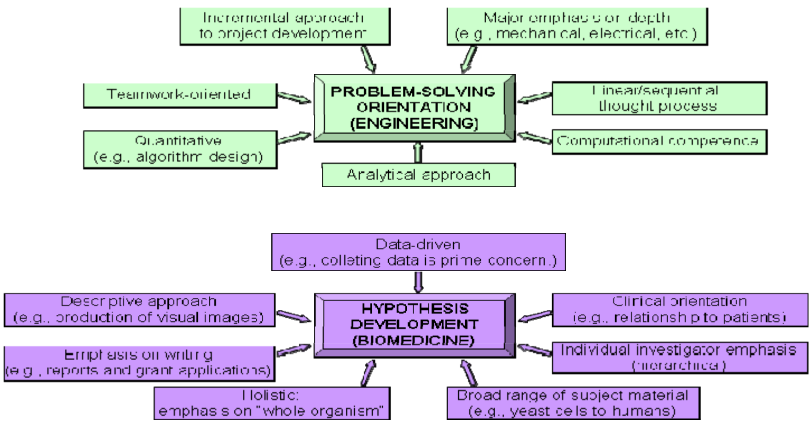

Figure 1. Skill sets that are emphasized during the training of engineers and biomedical researchers. Traditional engineering curricula have emphasized a "problem-solving orientation", whereas contemporary biomedical are emphasizing "hypothesis development".

So-called "systems biology" represents one area where a merging of engineering and biomedical skill sets is already underway. This endeavor emphasizes describing all of the interactions which occur between components (e.g., metabolites, enzymes, or nucleic acids) that are responsible for a specific physiological function or behavior pattern, either in individual types of cells, or whole, multicelluar organisms. Many of the most successful projects use genomics as a starting point for data interpretation. The quantitative and computational skills of the engineer are needed just as much as experimental and data collecting skills of the medical researcher. Examples of successful systems biology approaches are included in [7 and 8].

As a starting point for merging the two skill sets illustrated in Figure 1, Figure 2 indicates areas where the overlaps might be quickly achieved. For some projects the upper right to lower left overlap axis would be the most appropriate (e.g., mechanical engineers bringing their mechanics, instrumentation, and measurement expertise for creating replacement cells, tissues, and organs). In other instances, the lower left to upper right axis might be initiated by medical researchers to recruit mechanical engineers to molecular signaling pathway projects. The desired outcome of course is a multiplier effect for both mechanical engineering and medical research projects.

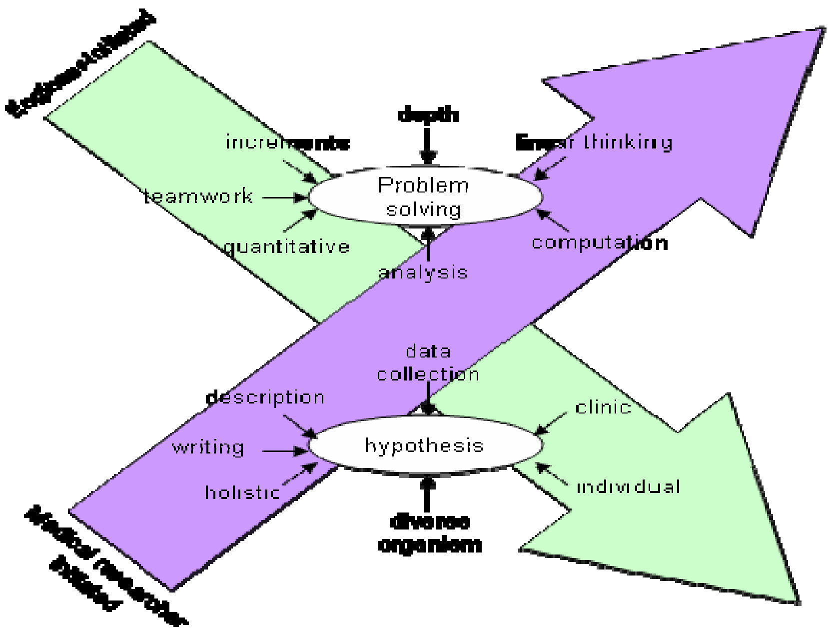

Figure 2. Potential areas for enhanced complementation and overlap between the emphases of engineering and biomedical training programs illustrated in Figure 1. The mechanical engineer's traditional strengths in areas such as solid and fluid mechanics, biomechanics, design of artificial organs and prostheses, measurement technology, and control systems involve conceptual and intellectual approaches which can be merged (upper left towards lower right) with medical emphases to great advantage. Conversely, a merging in the direction of the lower left to the upper right offers further advantages.

Working against that favored outcome are several factors. Often the group leader, who is ultimately responsible for mentoring a newcomer, lacks time to spend at the bench to provide the necessary advice and encouragement. The so-called "tournament model" (competition within the laboratory group [9]) therefore comes to dominate interpersonal relationships and the potential impact of the newcomer is never realized. As well, advancement criteria in academic medicine tend to be short-sighted by emphasizing publication records, thereby compromising originality and innovation.

OPPORTUNITIES FOR TRANSITIONING

Crossover research opportunities for engineers are plentiful

Below are listed several general areas for crossover research that might be activated in either of the orientations illustrated in Figure 2:

> <u>Computer simulations for developing theoretical frameworks</u> for molecular biology experimentation. Included could be emphases on feedback loops, intrinsic hierarchical design features, and assessments of the consequences of local failures in specific components. Several contexts/disease conditions are amenable to this approach, including alcoholism, diabetes, Parkinson's disease, etc.

> <u>Fundamental biological systems engineering.</u> Analysis of data from gene expression studies (e.g., gene micro array studies) or protein interaction maps (e.g., yeast 2-hybrid screening) in order to understand the functioning of metabolic pathways is eagerly awaited.

Instrumentation, measurement equipment, biosensor development. Designing "next generation" (micro/nano scale) techniques for monitoring physiological responses to drug therapy represents an area in great need for the types of innovation crossover research can generate.

Tissue engineering and biomaterials. The design of replacement tissue and organs requires not only expertise in cell function but also consideration of structural features of biomaterials. Mechanical engineers often are uniquely qualified to provide the requisite expertise.

RECOMMENDATIONS

An effective agenda for promoting successful transitions requires multiple strategies

Long term planning should of course characterize all serious attempts at facilitating the transition of mechanical engineers to biomedical research projects. Such long term plans require formal institutional guidance and include relocating engineering departments to physical facilities that are (preferably) housed directly within medical research buildings, or at the least, in adjacent locations. That is, the formal integration of engineering teaching and research venues in the midst of medical research complexes is required in order to facilitate integration and counteract the "addendum approach" (in which a discipline is "attached" more as an appendix rather than as a fully integrated component).

Needless to say, for complex reasons that are beyond the scope of this essay, such long term planning will require difficult negotiations, compromises, and macro-cultural changes, especially on the part of medical research enterprises.

In the short term, however, various steps can be implemented at both the medical sciences department level and at the level of individual medical research groups. These include the following:

1. Encourage research group leaders to insure that an "engineering newcomer" receives adequate mentoring from an experienced project manager, to help combat the dominance of the "tournament model" which characterizes much of modern life sciences research.

2. Organize support groups within a department for "in-transition" engineers to openly discuss the topic of "fear of failure/fear of change". Such fears are often described as a major impediment to "thinking outside the box" (e.g., [10]).

3. Enroll mechanical engineers, who are interested in medical research collaboration, in formal medical research seminar courses, in order to encourage them in achieve a broad understanding of the thought processes of medical researchers.

4. Require a "context review" at start of each laboratory research group meeting, to acquaint engineers with the conceptual background of a research project.

5. Allow crossover engineers to participate in writing grant proposals and to review manuscripts.

6. Introduce transitioning engineers to patients -- they might be inspired by human contact, and thus develop the motivation to excel in their new research project.

The main goal of those recommendations is of course to facilitate the enhancement of the overlapping, both at the formal, academic level (macro-level), and also at the level of individual research projects (micro-level) depicted in Figure 2. Any early training that the mechanical engineering degree programs can provide to students in their curricula will help this merging of cultures happen faster and more effectively. As alluded to in the National Academy of Engineers report of 2004 [11], the challenge for engineering education is to insure that the core knowledge advances in several of the emerging technologies, including biotechnology, are delivered to engineering students so that they can leverage them to achieve interdisciplinary solutions to engineering problems in their engineering practice. Successful mechanical engineers of the future in this area will be the ones who will gain this knowledge and training during the early years of their education without sacrifices from traditional mechanics approach.

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