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# Medicine on a need-to-know basis

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**Disease-oriented, introductory medical curricula can help overcome educational and institutional barriers that separate aspiring translational scientists in PhD programs from the world of medicine.**

The application of new advances in biosciences, informatics and engineering to the clinic is hampered by a lack of scientists familiar with medicine. Combined MD-PhD programs educate a small number of clinician-scientists who take leading roles in 'translational' medicine, but that approach is expensive and neglects the needs of many PhD scientists who wish to do translational work without becoming clinicians. We have identified key medical skills required for translational scientists and propose that they can be taught in PhD training programs through focused curricula. Here we describe an 'Introduction to Medicine' course that focuses on diabetes to teach graduate students a strategy for learning about any disease.

## The societal need

Basic discoveries have fueled medical progress throughout history. Today there is a growing consensus that ever closer interactions between clinical medicine and basic and engineering sciences are needed to realize the potential clinical benefit of research progress in many areas[1–4], including basic immunology. An interdisciplinary approach to present medical problems is particularly important because of the complexity of multifactorial, chronic diseases, which constitute a substantial proportion of the disease burden in developed countries[3,4]. However, interdisciplinary approaches are hampered by increasing specialization, driven by explosions of knowledge in both medical and nonmedical fields[5]. Therefore, future progress in addressing complex medical problems will come, as a rule, not from individual, broadly trained clinician-scientists but from interdisciplinary teams, comprising physicians and translational scientists: experts in other fields, such as basic physical and biological sciences, engineering and computer sciences, who apply their knowledge to medical problems without necessarily being physicians themselves[4,6,7].

The effectiveness of interdisciplinary teams will depend considerably on the ability of experts from disparate fields to communicate with each other and with physicians across the linguistic, cultural and institutional barriers of their disciplines[1,8]. Whereas medical students receive some training in relevant sciences during their undergraduate and medical education, and medical educators recognize the challenge of training physicians to keep abreast of scientific advances[8,9], at present there are few opportunities for students in translational science disciplines to be introduced formally to medicine[2]. That gap in our educational infrastructure poses a barrier to entry for aspiring translational scientists and a bottleneck in translating preclinical knowledge into clinical applications, which is increasingly being recognized as a funding priority, for example, by the Howard Hughes Medical Institute (http://www.hhmi.org/grants/pdf/comp_annc/2006_medintograd_program.pdf) and the National Institutes of Health (http://grants.nih.gov/grants/guide/pa-files/PAR-04-148.html).

## The educational challenge

Many graduate students in immunology and other disciplines relevant to translational medical research view their lack of medical training as an unmet need. We were first alerted to this in 2000, when several students from the Immunology Graduate Program at Stanford University explained that although they felt well versed in the molecular biology of immune responses, they were also interested in being taught, for example, how to interpret histological sections of pancreata or how animal models of diabetes relate to human disease. Similarly, graduate students in bioengineering and bioinformatics were aware of their limited formal preparation for working on medical problems. Most of these students were not interested in obtaining an MD degree, but sought alternative means of meeting their desire for medical education. Of course, the absence of programs has not prevented individual, highly dedicated translational scientists from contributing to medicine, but formal training related to medicine might well have eased their entry into the field.

Until recently, MD-PhD programs represented the only systematic effort at medical education for translational scientists. Those programs have produced a select group of academic medical researchers who have made enormous contributions to translational medicine. As a solution for the training of translational scientists, however, MD-PhD programs have several drawbacks. The MD and PhD components are not necessarily well integrated into a 'holistic' training experience for translational scientists. Clinical

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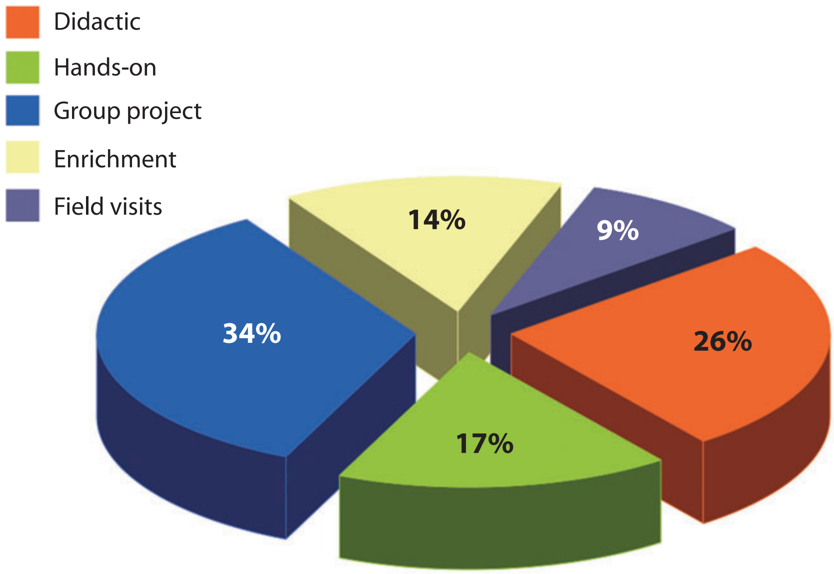


**Figure 1** Instructional components of the Introduction to Medicine curriculum. The course encompasses lecture presentations by content experts (Didactic); guided exposure to medical tools and resources (Hands-on); problem-solving in an interdisciplinary team setting (Group project); supplementary learning (Enrichment); and direct observation of clinical environments (Field visits).

decision-making, taught during MD training, involves the application of a body of well established medical knowledge to an uncertain, real-world context. In contrast, basic research during PhD training involves the design of highly controlled experimental settings with which new knowledge can be created. Neither component, however, provides specific training in the 'bridging' skills needed to bring basic advances to the clinic: physician training tends to neglect emerging fields that may provide new solutions, whereas basic sciences tend to be taught with less regard for applications and the complex issues associated with diagnosis and treatment of human disease[10].

Although those problems are beginning to be addressed by evolving MD-PhD curricula[11], others are inherent in the MD-PhD paradigm. MD-PhD programs are unable to train enough translational scientists, as they are generally slow and expensive and enrollment is decreasing[3,6]. Moreover, they require students to commit substantial time and effort to broad clinical training, generally unnecessary for translational scientists who do not wish to practice medicine. Finally, the academic culture of medicine and basic biological and computing sciences tends to reward individual contributions over those made with a team, although that is not true for engineering[1,6]. Thus, if more PhD scientists are to be attracted to team-based translational work, a new educational approach to their medical training is needed. Ideally that approach would be integrated into existing graduate programs without overburdening students, would set learning goals matched to the unique needs of translational scientists and would emphasize the power of a team approach to solving medical problems.

## Medicine for translational scientists

The medical learning needs of translational scientists and clinicians differ. One quantitative difference is that most translational scientists work on one or a few specific diseases, whereas even physicians practicing in subspecialties see patients with a broad range of conditions. Thus, comprehensive knowledge of many diseases is far less important to translational scientists. However, their knowledge of specific diseases and related subject matter may need to be as detailed as that of clinicians, if not more so; in addition, they may draw on more diverse sources of medically relevant information and have a greater need to consider emerging knowledge. The disease areas in which a translational scientist may work are not known in advance and may change during his or her career. Thus, rather than focusing on the specifics of particular diseases, the capacity to learn about any disease and to evaluate medical information critically should be developed.

Moreover, medical knowledge serves different purposes for clinicians and scientists. Clinicians need it mainly as a basis for making decisions about the diagnosis and treatment of patients. Conventional medical curricula are geared toward building those skills. Translational scientists, in contrast, need medical knowledge mainly to allow expert skills in nonmedical disciplines to be applied to a chosen, specific medical problem. For that use of medical information, those scientists need a general framework on which a detailed, disease-specific fund of knowledge can be built as needed. That conceptual framework also includes 'meta-medical' knowledge and skills, some of which are taught implicitly in traditional medical training but need to be made explicit to those without medical training. For example, translational scientists need to understand how medical information is organized; how different preclinical and clinical disciplines contribute to the understanding, diagnosis and treatment of a disease; who does what in a medical clinic; and so on. They need to be able to locate medical information from diverse sources and to evaluate its quality, reliability and limitations. Physicians and translational scientists also have different goals in interacting with patients; accordingly, their exposure to clinical environments serves different purposes. Physicians work with patients and other doctors to meet immediate clinical goals (to obtain medical histories, to observe signs and symptoms, and to communicate about and apply treatment). In contrast, translational scientists might talk to patients, for example, to sharpen their understanding of patients' practical problems in dealing with a disease, to obtain feedback on how their inventions benefit patients, and to boost their motivation for working on problems of human relevance. Based on all of those considerations, we sought to develop a means of introducing translational scientists to medicine.

## A disease-focused medical curriculum

We designed a curriculum specifically tailored to meeting those needs at the graduate level in a short period of time. A course covering that curriculum has been taught through the Graduate Programs in Immunology and Biomedical Informatics at Stanford University for the past 5 years. The student population consisted mostly of PhD, master's of science or combined bachelor's of science–master's of science students (83%); some were undergraduates (7%); and 11 students were working, almost all in industry. Of the last group, some used an online learning option offered through the Stanford Center for Professional Development. The students were drawn in roughly equal proportions from basic biosciences (29%), engineering disciplines (34%; mostly biomedical and mechanical engineering) and computer sciences (33%; mostly biomedical informatics, a program for which this course was a requirement). A total of 111

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students have been taught so far, and the course has been iteratively refined.

Our goal was to impart the skills and knowledge required for those students to learn about any disease area in sufficient depth to apply their main expertise to unsolved problems in this area. To organize the relevant information, we used one disease as a paradigm for how any disease might be approached. Although this is to our knowledge the first use of the paradigmatic approach for training translational scientists, this approach is not conceptually new in medical education. At the turn of the century, William Osler proposed the use of syphilis as a model disease when teaching medical students, pointing out that syphilis was "…the only disease necessary to know. One then becomes an expert dermatologist, an expert laryngologist, an expert alienist, an expert oculist, an expert internist, an expert diagnostician."[12] We chose diabetes mellitus as a paradigmatic disease for many reasons, including its importance to public health; its etiological heterogeneity and complexity; its ability to affect multiple organ systems through long-term complications; the intricacy of the metabolic systems dysregulated in diabetes; the wealth of existing and emerging therapeutic options; and the number and complexity of remaining clinical challenges. In sum, although other choices would have been plausible, diabetes exemplifies a disease area on which translational scientists are likely to have an effect and demonstrates the complexity of the problems they are likely to encounter.

In organizing a diabetes-focused curriculum, we sought to emulate how a translational scientist might learn about a disease (**Fig. 1**; further details, http://imed.stanford.edu). The course, which is taught in 40 hours of class time (one academic quarter with 4 hours per week), begins with introductory material about diabetes, delivered through lecture presentations by endocrinologists and diabetes educators who are also patients, providing a highly motivating human element. This material, supplemented by readings from the lay press, outlines the problem area. A visit to a diabetes clinic allows first-hand exposure to practical problems faced by clinicians and patients in managing the disease. Guided exposure to sources of medical information includes a review of the content of medical records, a session on how to read a clinical paper, and a computer laboratory session on relevant databases and searching strategies taught by a medical librarian. Other lectures show how various medical sciences (epidemiology, genetics, physiology, anatomy and pathology) provide complementary perspectives on diabetes. This part of the curriculum is reinforced by visits to clinical diagnostic and anatomy laboratories. The students also have a 'hands-on' session using software from Entelos, a company specializing in physiology modeling.

In the last half of the course, the lectures focus on the structure, function and pathophysiology of the main organ systems affected by the long-term complications of diabetes (the cardiovascular and nervous systems, eye and kidney) and on their clinical effect and management. During these sessions, students are instructed in parts of the physical examination particular to each subspecialty (such as auscultation and retinal exam in the sessions on cardiology and ophthalmology, respectively). A 'journal club' with student presentations on emerging therapeutic approaches allows them to demonstrate their growing comprehension of diabetes-related medical literature. The course ends with lectures on healthcare systems and healthcare economics. The lecture material is supplemented by a 'course reader' and additional online resources. Overall, the course content emulates the iterative deepening and progressive broadening of an initially crude understanding of a disease, resembling the process by which a translational scientist might teach himself or herself about an unfamiliar disease.

To provide an opportunity for students to apply their primary disciplines to medical problems, the students are asked to form

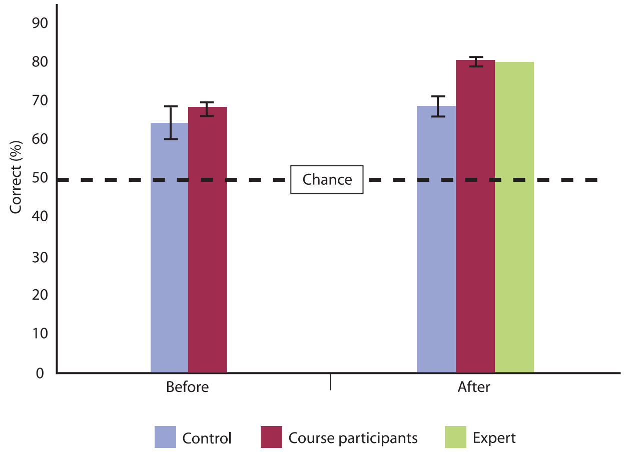


**Figure 2** Assessment of the knowledge of diabetes and general medical subjects. Performance of Introduction to Medicine students (Course participants; $n = 42$), students in the same graduate programs but not enrolled in the class (Control; $n = 4$) and a physician (Expert; $n = 1$) on a multiple-choice questionnaire before (left) and after (right) completion of the course; scores were assigned as mean (± s.e.m.) percent correct answers. $P < 0.001$ after completion of the course (*t*-test), and $P = 0.508$ at the beginning of the class, Introduction to Medicine versus control students. Selecting answers at random would have yielded 49.3% correct answers (Chance); 93 items were true-false items, and the first three items had five, three and four answers as choices, with only one being correct: $[93 \times (0.50) + (1/5) + (1/3) + (1/4)] / 96$.

**Table 1 Problem areas and student projects**

| Problem area | Student project |
|---|---|
| Design device improvement for continuous glucose monitoring that extends its working life in the body | The 'GlucoTongue', a passive indwelling glucose meter |
| Propose approach for increasing the supply of human islets of Langerhans or beta cells for transplantation, or an approach for increasing insulin production | A system for large-scale isolation and microencapsulation of humanized islets derived from transgenic tilapia fish for xenotransplantation into patients with type 1 diabetes |
| Identify specific complication of diabetes and design innovative approach to diagnosis or therapy | Automated diagnosis of retinopathy for early screening |
| Design approach for identifying genes involved in diabetes susceptibility in population with a high incidence of diabetes | A functional screen for genes involved in beta-cell dysfunction using RNA silencing |
| Design new drug therapy for type 2 diabetes | Treatment of type 2 diabetes by recombinant adeno-associated viral delivery of modified insulin promoter factor-1 |
| Develop an interface for vision-impaired patients | 'Intelli-Pump', a voice-activated insulin pump |

## BOX 1 EXAMPLES OF MULTIPLE-CHOICE QUESTIONS ABOUT DIABETES AND GENERAL MEDICINE

1. *(Circle the best answer)* If a person with diabetes reports feeling shaky and weak or even dizzy, s/he is probably:
(a) Euglycemic; (b) Hypoglycemic; (c) Hyperglycemic.

2. *(Circle all that apply)* Why is a basal infusion of insulin necessary for people with diabetes who are on insulin pumps?
(a) It inhibits gluconeogenesis; (b) It prevents hypoglycemia; (c) Without insulin, the body reacts as if to starvation; (d) It prevents hypertension; (e) It raises glucose levels during postprandial periods.

3. *(Circle all that apply)* Atherosclerosis can be influenced by:
(a) Diet; (b) Genetics; (c) Smoking; (d) Shear stress at vessel junctions; (e) Recirculation.

4. *(Circle all that apply)* The prevalence of type 2 diabetes in the US in 1998 was about:
(a) 16 million people; (b) 800,000 new cases annually; (c) 90% of all cases of diabetes; (d) 50 million people; (e) 200,000 new cases annually; (f) 60% of all cases of diabetes.

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interdisciplinary project teams at the beginning of the term. Each team selects a broad problem area in the early detection or management of diabetes or its complications from a list of choices (**Table 1**). That problem area is then explored by the students, with help from project coaches (students who have already completed the course) and, if needed, from medical faculty. The students are directed to investigate the problem area, to define a 'subproblem' that can be approached within the time limits of the class, to review existing or emerging solutions to the problem and their limitations and to propose a new solution. The products of the project work (midterm and final reports, oral presentations and, optionally, prototype development) are subjected to detailed feedback by fellow students and faculty. Through the projects, which consume most of the students' out-of-class study time, the students are trained to function as translational scientists in a previously unfamiliar disease area.

### Assessing learning outcomes

We have used many different approaches to evaluate learning outcomes from the course; here, we outline the evaluation strategies and briefly summarize the results. Both by their own assessment and as judged by their performance on multiple-choice tests, the students acquired substantial, detailed knowledge about medicine in general and diabetes in particular. When questioned at the beginning of the course, the students had a low opinion of their own knowledge of these subjects. In a multiple-choice test intended to probe the students' knowledge of diabetes and medicine (**Box 1**), they scored somewhat better than they would have by randomly selecting answers but no better than other graduate students who had not elected to take this class (**Fig. 2**). There did not seem to be self-recruitment of students with superior starting knowledge. At the outset, students fell short of the performance of a physician who took the test as a positive control. Our impression was that the students' starting level of knowledge of medicine and diabetes was comparable to that of an educated layperson. When the exam was repeated at the end of the class, the performance of course participants had risen to match that of the physician (**Fig. 2**). When asked to assess their learning gains on a scale of 1 to 5 through the Student Assessment of Learning Gains, an internet-based questionnaire (http://www.wcer.wisc.edu/salgains/ftp/SALGPaperPresentationAtACS.pdf), they reported substantial gains in their knowledge of diabetes (average score, 4.1) and of medicine in general (average score, 3.7) and increased confidence in their ability to learn about previously unfamiliar diseases (average score, 3.8). That increased confidence might be considered a useful learning outcome, as one goal was to reduce barriers to entry into translational work. When asked to rate each course component for its utility, each component was judged to have contributed, albeit to varying extents (average score, 3.3–3.9; the sessions on 'Diabetes from a patient's perspective' and 'Pathophysiology of type 1 diabetes' received the highest scores).

Though not quantifiable, perhaps the most compelling evidence of the success of our approach comes from the quality of the students' project work. Even at the midterm stage, the specific project topics defined by the students showed that most students had begun to understand the underlying medical problems in some depth (**Table 1**). The quality of the final oral and written presentations resoundingly confirmed that impression (sample projects, http://imed.stanford.edu). The projects were in some cases sufficiently novel to obtain provisional patents. That prompted the inclusion of supplementary sessions on intellectual property and a 6- to 8-hour self-taught online 'mini-course' on biomedical entrepreneurship, developed in collaboration with the Stanford BioDesign Program. Finally, the solutions to the medical challenges incorporated elements derived from the students' main disciplines, demonstrating that the project teams not only had succeeded at becoming problem solvers in the medical arena but also had begun to function as translational scientists by applying their discipline-specific knowledge.

Although it is too early to assess fully to what extent the course attracted students into translational medicine as a career, early signs are promising. In follow-up surveys sent in 2005 to students from the first 5 years of the course (response rate, 57%), we found that 46 of 48 respondents planned to pursue research in some setting, and of those, 91% intended to do research related to human health. Among all the respondents, 43% reported that the course affected their career decision and 57% felt that it enhanced their research efforts.

### Adding depth and breadth

A large proportion of survey respondents (88%) felt that additional exposure to medicine would have been useful to their growth as translational scientists, raising the issue of how this introductory curriculum might be expanded. For students wishing to continue their project work in a structured environment, a follow-up class based entirely on projects has been useful. In addition, medical school classes or more exposure to clinical environments may be of benefit to those students who want to extend the didactic portions of the Introduction to Medicine class and who will now be better prepared to make use of these learning opportunities. For example, at Stanford, participation in a new Masters of Science in Medicine program will be offered to six to ten bioscience PhD students per year, beginning in 2006. Those students will take basic biomedical science courses with the medical students, including anatomy, physiology, genetics, immunology and pathology, before starting their PhD thesis work. They will also choose physician mentors, who will help design a 1- to 2-month clinical experience for them (http://msm.stanford.edu). The joint Harvard–Massachusetts Institute of Technology PhD program in Medical Engineering and Medical Physics has a similar structure and includes a 4-month clinical component[2].

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### Institutional context

Future efforts toward developing innovative cross-disciplinary medical curricula are likely to benefit from an institutional environment dedicated to interdepartmental and interdisciplinary 'cross-fertilization'. The design of the Introduction to Medicine curriculum at Stanford has been an interdisciplinary team effort in its own right, involving extensive dialog between members of the Stanford School of Medicine and of various science and engineering departments, as well as experts on interdisciplinary project work, curriculum design and educational outcomes research. Its implementation required considerable faculty commitment, financial support, information technology support from the medical school and the Stanford Center for Professional Development, and the willingness of the medical school to allow student access to clinics. The adoption of our Introduction to Medicine curriculum at other institutions, however, should be less demanding. We have adapted the class for 'distance' learning online; in this version, the students write a critical review of a project by an in-class team. In a pilot project with the University of Washington (Seattle, Washington), videotaped lectures have been made available as a basis for mentored video instruction, with good success.

### Concluding remarks

Our experience teaching the Introduction to Medicine course at Stanford demonstrates that the medical-education needs of translational scientists can be addressed successfully even in a limited amount of class time, if those needs are understood as being distinct from those of aspiring clinicians and if curricula are tailored to recognize that distinction. Of course, focused medical curricula for translational scientists are no substitute for the participation of medical experts in translational research teams. Indeed, in our course, project teams that actively sought ongoing input from physicians were among the most creative and successful. Instead, translational research will benefit from the reduction in communication barriers that impair the transfer of critical knowledge from physicians to other team members, enabling medical expertise to be used more efficiently.

Recognizing the unique educational challenges of teaching medicine to translational scientists is, in our opinion, key to overcoming a critical bottleneck in developing human resources for 'bench-to-bedside' research. Of course, there will be other obstacles. Traditionally, industry has been the most natural home for those dedicated to interdisciplinary teamwork in applied sciences. Bringing a similar spirit to academia will challenge departmental boundaries and funding mechanisms and an established culture that rewards individual success over team contributions[6]. However, interdisciplinary programs and centers have the potential to transform those aspects of academia, yielding a fertile environment for translational science.

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