"Genes to Society"—The Logic and Process of the New Curriculum for the Johns Hopkins University School of Medicine

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Abstract

In August 2009, the Johns Hopkins University School of Medicine implemented a new curriculum, "Genes to Society" (GTS), aimed at reframing the context of health and illness more broadly, to encourage students to explore the biologic properties of a patient's health within a larger, integrated system including social, cultural, psychological, and environmental variables. This approach presents the patient's phenotype as the sum of internal (genes, molecules, cells, and organs) and external (environment, family, and society) factors within a defined system. Unique genotypic and societal factors bring individuality and variability to the student's attention. GTS rejects the phenotypic dichotomy of health and illness, preferring to view patients along a phenotypic continuum from "asymptomatic and latent" to "critically ill." GTS grew out of a perceived need to reformulate the student experience to meet the oncoming revolution in medicine that recognizes individuality from the genome to the environment. This article describes the five-year planning process that included the definition of objectives, development of the new curriculum, commission of a new education building, addition of enhancements in student life and faculty development, and creation of a vertical and horizontal structure, all of which culminated in the GTS curriculum. Critical ingredients in meeting the challenges of implementing GTS were leadership support, dialogue with faculty, broad engagement of the institutional community, avoidance of tunnel vision, and the use of pilot courses to test concepts and methods. GTS can be viewed as the foundation for the scientific and clinical career development of future physicians.

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The Flexner Report,[1] published in 1910, stressed the importance of science for medicine and catalyzed a revolution in medical education. A century later, with genomics catalyzing a revolution in biomedical research in an environment of accelerating social and economic change, many have argued it is time for another sea change in medical education.[2] To this end, we proposed a new conceptual framework for the medical education curriculum, to be based on principles of biologic and environmental individuality. A major goal of this new curriculum is to reframe the context of health and illness more broadly, to encourage medical students to explore the biologic properties of an individual's health in the light of a larger integrated system that also includes social, cultural, psychological, and environmental variables.[3,4] The Johns Hopkins University (JHU) School of Medicine has implemented a curriculum that is based on this framework, so as to prepare medical students for an era when patients will expect "individualized" medicine and physicians will have the tools in hand to provide such care.[5,6]

This curriculum, called "Genes to Society" (GTS), is based on the precept that genetic, environmental, and societal influences are subject to variation. These variations lead to the enormous heterogeneity of health phenotypes. Our thinking in this regard has been greatly influenced by the ideas of Barton Childs[7] and his advocacy for genetic thinking in medicine. The physician's classic perspective is "What is wrong, and what can I do?" Some of us suggested, instead, that physicians should be taught to ask, "Why does this particular person have this particular disorder at this time?" or "Why is my patient at risk for developing certain problems and what can I do to prevent or forestall their onset?"[8] This "new" view of medical education derives from Sir Archibald Garrod[9] and his seminal idea of chemical individuality, which he first proposed in 1902. Only recently, however, has broad application of these concepts to medical education become feasible. The elucidation of the reference human genome sequence and the growing appreciation of the uniqueness of each person's version of this sequence, confirmed by recent sequencing of "personal genomes," have exposed the extent and complexity of genetic variation.[10–12] These variations affect every subsequent level of the biological hierarchy and each individual's interactions with his or her environment. Understanding the extent of this variation and how it influences the characteristics of biological systems is a key element of the GTS curriculum (Figure 1).

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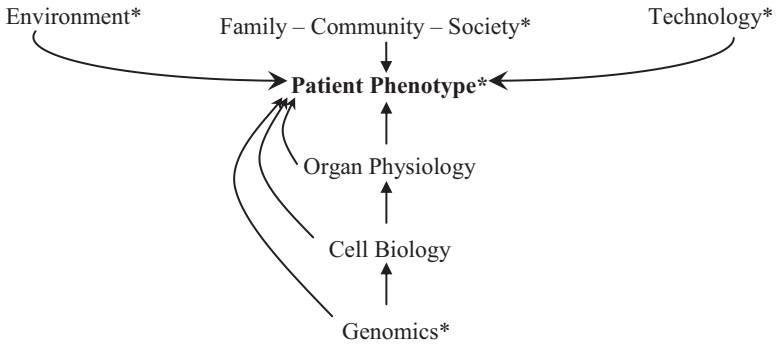

Figure 1 Contextual framework of the Genes to Society curriculum. An individualized patient phenotype is the sum of the internal (genome, proteome, cell, and organ) and external (environment, family, community, and society) elements of the patient. Environment may also influence protein expression via genetic or epigenetic effects. Components marked with an asterisk (*) are those components in which significant variation affects phenotype.

Individuality and the Impact of the Human Genome Project

The biomedical watershed of complete identification of the reference human genome sequence and the subsequent elaboration of millions of individual differences are confirming what astute clinicians had long suspected—namely, that every patient is unique.[13] Whereas the DNA sequences of all humans are more than 99% identical, several million differences exist between the genome of one person and that of another, in the form of single-nucleotide polymorphisms (SNPs) and copy number variations (CNVs) that provide the genetic contribution to individuality.[14,15] When coupled with the unique histories of environmental and social experiences characteristic of each of us, SNPs and CNVs may explain individual variation and clarify why some persons get sick while others remain healthy. Our understanding of the human disease or risk phenotype as a dynamic interplay between the unique biologic and environmental characteristics of an individual is advancing at a rapid pace.[16–18]

Moreover, the variation in the protein products of genes plays out in the behavior of complex biological systems made up of these proteins. Knowledge of how this variation affects the properties of these biological systems (called "systems biology") will be important for gaining an understanding of the dynamic state of an individual's health. Systems biology strives to understand the properties and behaviors of biologic systems and uses techniques extending from genomics through epidemiology to improve our understanding of the determinants of the balance between health and disease.[19–21]

Future physicians will integrate individual bits of evidence into a biologic system that extends from genes and the genome, proteins, cells, tissues, and organs (internal elements) to the environment and society (external elements). The elements of the system combine into individual phenotypes, which the future physician must recognize, understand, and manage. Similarly, physician–scientists will interpret their discoveries in basic, translational, and clinical research in the same context, thereby promoting more effective strategies for improving health. It is our goal at JHU School of Medicine to educate future clinicians and physician–scientists in the GTS perspective and to guide them to consider it an essential conceptual approach for translating basic science into physician practice.

The Curriculum Reform—Process and Challenges

Broad inquiry, complete involvement of all elements of the JHU School of Medicine, and some serendipity have marked our curriculum reform process. JHU is fortunate to have an institutional history of successful educational innovation, which provided an important context for the changes that were to take place.[22,23] Table 1 shows a chronology of curriculum reform, emphasizing the key events and the underlying principles they represent.

In 2002, the chair of the Department of Pediatrics handed the vice dean of education a recently published book entitled *Genetic Medicine—A Logic of Disease*,[7] which had been written by one of the department's faculty members, Barton Childs. Childs's thesis is that the basic structure of medical curricula is not suited to the nature and pace of scientific and societal changes, and his book offers a theoretical foundation for an alternative to the standard medical curriculum. This book made a deep impression on the vice dean, who launched a six-month strategic planning exercise involving educators, scientists, clinicians, patients, policy makers, and industry representatives to answer the question, "How will medicine be practiced in 10 years?" The JHU School of Medicine Office of Strategic Planning staffed the exercise and employed quantitative and qualitative methodologies. This group identified several events or trends—including the elucidation of the human genome, the aging of the population, the changing economics of health care, the increasing interest in public health and global medicine, and the rapid development of diagnostic and therapeutic technologies—that likely would affect the future practice of medicine and, therefore, the curriculum of medical schools. The vice dean presented the complete results of this exercise to the dean/chief executive officer of the JHU School of Medicine, the president of the JHU Health System, and the department chairs. The strategic exercise and the resulting institutional discussion led to a rough consensus among JHU School of Medicine leaders concerning the future scenarios of medical practice and scientific inquiry that medical students would have to be prepared to manage. There remained a major task of determining how, precisely, to educate these students for this anticipated future practice of medicine.

In 2003, the dean of the JHU School of Medicine convened a Curriculum Reform Committee (CRC) to evaluate the current curriculum and to recommend whether and, if so, how the medical school curriculum should be revised. An earlier (1986) curriculum reform at JHU had predominantly affected the first two years of medical school and did not change much in the format of the clinical years.[22] On the basis of the vice dean's strategic planning exercise, the dean charged a faculty-led committee to consider the rapidly

Table 1

The Process of Curriculum Reform That Led to Implementation of the "Genes to Society" (GTS) Curriculum at the Johns Hopkins University School of Medicine in August 2009*

Principle	Specific event or events	Date
An intellectual foundation	Childs BL, *Genetic Medicine—The Logic of Disease*, JHU Press	1999—Published 2002—Read by vice dean of the medical school
A strategic plan	To answer the question, "How will medicine be practiced in 10 years?" • Interview stakeholders • Review data • Develop scenarios	Fall 2002–Spring 2003
Leadership engagement	Presentation of strategic plan scenarios to institutional leadership	May 2003
A formal charge by the dean of the medical school	The dean charges a faculty-led curriculum reform committee (CRC) to report on how Johns Hopkins University (JHU) School of Medicine (SOM) will prepare students for the future practice of medicine	May 2003
Broad-based and dynamic composition of the CRC	The chair of the CRC recruits faculty from all departments (educators, clinicians, and scientists), residents, and students to join the CRC; the committee's composition expands and changes over time, depending on the need	May 2003–Jan 2005
Transparency and engagement of entire SOM community	• A general notice to all faculty and students • Posting of all CRC minutes on a Web site • Regular departmental and town hall meetings led by the chair of the CRC • Regular features on curriculum reform in JHU publications, including student newsletters • Repeated requests for faculty critiques and ideas • Periodic briefings for trustees and alumni	Sept 2003 Sept 2003–June 2007 Jan 2004–June 2007 Jan 2004–June 2009 Jan 2005–June 2009 Jan 2004–August 2009
Avoidance of tunnel vision	The CRC encouraged the institution to tackle related issues that affect successful curricula (e.g., teaching space, faculty promotion criteria, and faculty development) through the creation of separate committees	2006–2008
Clear milestones	Hand off responsibility from CRC to central administration (associate dean for curriculum) for implementation	June 2007
Integration	Careful integration of all course content achieved through the GTS Integration Committee, which reports to the Educational Policy and Curriculum Committee	Sept 2007–August 2009
Phased rollout and pilots	Pilot GTS courses allow refinement of principles and add momentum	May 2006–May 2009
Celebration	Launch of new curriculum used to celebrate education at the institution	October 2009

* JHU indicates Johns Hopkins University; SOM, School of Medicine.

changing scientific and social milieu and report back on how best to educate future physicians for practice in 10 years.

The initial CRC was small (approximately 15 members from diverse clinical and scientific backgrounds); for one year, it met every two months to assess whether a new curriculum was needed and, if so, what the needs of that curriculum would be. The recommendations of the earlier curriculum reform committee that had not been implemented were considered in those discussions.[22] At the end of that year, the committee's recommendation to the dean was a complete redesign of medical school curriculum, rather than a revision of the existing curriculum.

Over the next four years, the CRC grew substantially, to include broad representation from faculty and students, so that it could build on the initial vision. The JHU Bloomberg School of Public Health was a prominent partner in curriculum development. The CRC chair, the vice dean for education, and the dean of the JHU School of Medicine worked toward transparent and regular communication with all members of the School of Medicine community about curricular reform efforts. Once the dean endorsed the initial proposal of the CRC and it became apparent that this change was going to happen, more faculty and students became energized to participate in the development of the new curriculum. One of the original CRC members had coedited a major text on curriculum design and was able to write an early white paper on all of the items (beyond curricular content revision) that would be needed for comprehensive curriculum reform.[24] This white paper's recommendations included the creation of a new position of associate dean for curriculum and a new four-year college advising system for medical students, the development of centralized curriculum management software, online testing, and student portfolios, the provision of new teaching space, and a reevaluation and eventual rewriting of the promotion criteria for educators. After the entire CRC endorsed the contents of the white

paper, the dean formed new committees to review and implement these recommendations without waiting for the final CRC product.

The college system for teaching clinical skills and for more structured student advising was implemented in 2005.[25] The promotions guidelines were reformulated in broad terms to specify that, regardless of the faculty member's predominant activity, promotion to associate professor required evidence of a national scholarly reputation in that activity, and promotion to professor required evidence of national leadership in that activity.

The broad discussion of a new medical school curriculum was accompanied by a great deal of discussion among faculty and students about the conceptual framework for the design of the curriculum, the optimal method of teaching the new curriculum, the extent of the scholarly requirement, and the need for a structured, core, basic clerkship sequence and required advanced clerkships (neither of the latter existed previously). These discussions at the school, department, division, and student government levels led to continual refinement of the curriculum. The CRC chair and the vice dean held regular town hall and faculty meetings (usually attended by the dean) as well as annual schoolwide retreats to publicize the curriculum and receive faculty input on the pros and cons of various new curricular elements. Dedicated administrative support for CRC allowed the creation of a Web site and periodic newsletters to inform the community of the progress toward the planned revision.

From 2004 through 2007, the enlarged CRC broke down into smaller groups, who were tasked with actually formulating objectives for each new component of the curriculum. At that point, we had roughly outlined the new four-year sequence of courses and were asking faculty and students to begin the design of specific objectives and experiences. It became apparent that, whereas CRC members were focusing on the "vertical" concepts of GTS within each course or section, no one was looking horizontally at the integration of broad concepts over the four-year experience. We therefore created a new subcommittee of the CRC, called the Horizontal Strands Subcommittee. This group was charged with weaving into the entire curriculum themes that affect every course and clerkship. These themes fit into two categories: (1) social and behavioral strands (i.e., pain, patient safety, professionalism, epidemiology, nutrition, communication, cultural competence, public health, clinical reasoning, and human development) and (2) biomedical strands (i.e., genomics/proteomics, imaging [microscopic and macroscopic], informatics, molecular embryology, pathology, and pharmacology).

When it became apparent that the new curriculum would use nonlecture teaching methods to a larger extent than did the previous curriculum, we realized that the current medical school facilities would be inadequate for the new curriculum. We communicated regularly with the wider community of trustees and alumni about the proposed new curriculum and the updated facilities that the curriculum would require. A few weeks after a presentation on curriculum reform to the board of trustees, the dean received a call from the chair of the board, who offered to make a substantial gift toward a new medical education building. We were now able to simultaneously design the curriculum and the building to allow incorporation of new teaching techniques, such as team-based learning, learning studio presentations, group computer work, electronic white boards, and microsimulations. One floor of the new building was dedicated to the colleges to provide space for community events as well as group and individual study. The new building, dedicated solely to medical student education, opened at the same time as the rollout of the GTS curriculum, in August 2009.

With the new pedagogy, preclinical content, scholarly requirements, intersessions, required clerkship material, and advanced clerkship material, there is a major need for faculty development. During the past four years, the medical school has sponsored workshops, retreats, and trial classes to introduce faculty to the new curriculum and its pedagogical needs. We view this as an ongoing challenge because the mandate for less lecture time and greater faculty supervision of clinical clerkships will require more faculty time. In addition to seeking private support for the new education building, the dean and the board of trustees are continuing their efforts to find private support for faculty education time and career development. Along with its efforts with respect to the financial support of faculty teaching, the institution has been working to better assess and reward teaching in the promotions process. This task is complex because our institution has maintained a single-track promotion system with delineation of potential paths to promotion that allow for diverse faculty activities.

During the last year of the CRC, academic year 2006–2007, the faculty and students broke into subgroups by course, section, and horizontal strand to finalize educational strategies for each component of the curriculum. At this time, plans were made for the complex transition from the old curriculum to the new, including the initiation of funding for continued planning. After approval of the GTS curriculum by the advisory board of the medical faculty, the CRC was disbanded in June 2007 and was replaced with the GTS Integration Committee. This group comprised all of the course directors of the new curriculum as well as the leaders of the Horizontal Strand Subcommittee. Chaired by the associate dean for curriculum, this group meets bimonthly and is responsible for implementing the new curriculum, a task that includes curriculum management, budget allocations, transition planning, faculty development, and building utilization.

Curriculum Design and Implementation Challenges

Some faculty and departmental resistance to change did arise from time to time. During the first few years of curriculum reform, some basic science faculty objected to GTS concepts as the basis for curriculum reform. This period coincided with the publication of the NIH Roadmap.[26] The objections to the GTS approach were similar to those directed against the Roadmap—namely, that the translational, integrated approach that replaced separate courses in the traditional disciplines (e.g., pharmacology, physiology, and pathology) would undermine understanding of these disciplines. Time allocation also disturbed faculty in some

of the disciplines. The inclusion of eight weeks of integrative multidisciplinary content in the intersession weeks in the first two years meant that less time was allocated to biomedical science. However, basic science departments assumed the leadership of the translational intersessions in the third and fourth years. Thus, most basic science faculty appreciated that the GTS curriculum as a whole not only emphasized basic science but also afforded an opportunity for basic science faculty to bring the very latest research results to the students at a point when they had developed the much more sophisticated framework needed to absorb such information.

Later in the process, it was the clinical departments' turn to object to various decisions about which clerkships would get more or less time in the new curriculum. Some departments felt that the integration of content typically associated with a given department would weaken the students' identification with that department as a whole. Constant dialogue, beginning with a focus on everyone's genuine desire to do what was best for the students, provided the only avenue to solutions.

The participation of graduate students in medical student education was another thorny problem. The old curriculum made such participation easy because the curriculum largely was departmentally based, but a fully integrated, systems-based curriculum presented challenges. The solutions have been incremental. The medical education building was designed to continue to allow joint graduate and medical student classes. Graduate and medical education schedules were coordinated whenever possible so that highly specialized facilities (e.g., the anatomy lab) are available for graduate education. Graduate students remain welcome in GTS courses that fit their needs. However, the graduate school is now engaged in its own curriculum reform exercise to reevaluate its needs for the future.

The availability of adequate funds to implement an entirely new curriculum is an ever-present challenge. Very close cooperation between the office of the vice dean for education and the finance office allowed annual and 5- and 10-year projections of the costs of the new curriculum, which were then incorporated into the school's overall finance plan. The newly created position of assistant director of finance focuses solely on education and reports jointly to the vice dean for education and the chief financial officer. Perhaps the most important approach was the dean's directive to concentrate on excellence of medical education. The inevitable trade-offs based on cost would be made at the end of the process, not at the beginning or even during the curriculum reform process.

The GTS Curriculum—Structure and Content

The GTS curriculum began in August 2009 with a firm grounding in basic science (Chart 1). The curriculum started with the Scientific Foundations of Medicine (SFM) course that will teach state-of-the-art basic science but also will stress individual variation and the continuum between health and disease. The foundational concepts introduced during this period will be revisited and enhanced throughout the curriculum. In addition to the natural sciences, SFM will incorporate the social and medical humanities to show the profound impact of social, cultural, and environmental factors on biologic processes. At the same time that they are taking the SFM course, students will begin developing communication and physical examination training in the Clinical Foundations (CF) course. Moreover, in the Foundations in Public Health (FPH) course, students will begin the longitudinal behavioral and social science curriculum that, at the outset, will emphasize basic principles of ethics, public health, and global health. A goal of this initial four-month period that includes the SFM, CF, and FPH courses is to heighten students' awareness of the interaction of the natural, humanistic, and social sciences with medicine.

After completion of the three foundations courses—or at a point roughly four months into year one—the students will begin a 15-month course designated the GTS course. This course will be organized by organ system, with each section of the course considered as a continuum from genes and biological systems through to the social and cultural factors that influence health (Chart 1). The GTS course will reinforce the principles of variation and individuality introduced in the SFM course and will eliminate the often artificial dichotomy between normal and abnormal biologic function, emphasizing instead the spectrum of function, whose manifestations range from illness to well-being. This content will necessarily involve faculty from many different disciplines and will have the additional benefit of integrating basic science and clinical faculty into new groups dedicated to teaching a particular system. It is important that, throughout the GTS course, each organ-system section cover relevant core concepts extending from molecular science through biologic systems and public health. For example, the section on infections and immunology will address the topic of vaccination, from basic immunologic responses through cost-effectiveness and implementation. While they are taking the GTS course, the students will be exposed to a wide range of clinical problems in their Longitudinal Ambulatory Clerkship (LAC), which meets for half-a-day a week from the middle of the first year through most of the second year. The direct clinical and scientific exposures provided by the LAC and the GTS course will allow each of these experiences to highlight the relevance of the other to medicine.

A second strategy for emphasizing and exploiting synergies between clinical medicine and basic science involves a series of eight 1-week intersessions, interspersed throughout the GTS course in years one and two, that use clinical themes (e.g., patient safety, pain management, and health care disparities) to explore scientific content and social consequences (including safety, cost, ethics, and policy). As described below, these intersessions continue through years three and four, but their emphasis changes to a focus on the relevance of basic science to specific clinical problems (e.g., diabetes, cancer, and inflammation).

While they are taking the GTS course, and during a period spanning the summer between years one and two, all students will be required to enroll in the Scholarly Concentration (SC) series of seminars and mentored scholarship opportunities. The SC course allows the student to explore research in one specific element of the GTS continuum under the guidance of a faculty researcher

Chart 1

The Johns Hopkins University School of Medicine Four-Year "Genes to Society" Curriculum, Implemented in August 2009*

<table>
<tr><td colspan="14">Year 1</td></tr>
<tr><td colspan="3">4 months (mid-August – mid-December)</td><td colspan="8">5.5 months (January – mid-June)</td><td colspan="3">9 weeks of summer</td></tr>
<tr><td>Intersession</td><td>Foundations: Scientific, Clinical, Public Health</td><td>Intersession</td><td>Break</td><td>Genes to Society
Longitudinal Clerkship
Scholarly Concentration</td><td>Intersession</td><td>Genes to Society
Longitudinal Clerkship
Scholarly Concentration</td><td>Break</td><td>Genes to Society
Longitudinal Clerkship
SC</td><td>Intersession</td><td>Genes to Society
Longitudinal Clerkship
SC</td><td>Intersession</td><td colspan="2">Summer</td></tr>
<tr><td colspan="14">Year 2</td></tr>
<tr><td colspan="6">7 months (August - February)</td><td>March</td><td colspan="7">4 months (April – July)</td></tr>
<tr><td colspan="2">Genes to Society
Longitudinal Clerkship
Scholarly Concentration</td><td>Intersession</td><td colspan="2">Genes to Society
Longitudinal Clerkship D
Scholarly Concentration</td><td>Break</td><td>Intersession</td><td colspan="2">Genes to Society
Longitudinal Clerkship
Scholarly Concentration</td><td>Transition to Wards</td><td>Break</td><td colspan="3">Basic Clerkships, including Intersessions and PRECEDE
Electives
Advanced Clerkships</td></tr>
<tr><td colspan="14">Year 3</td></tr>
<tr><td colspan="14">12 months (September – August)</td></tr>
<tr><td colspan="3">9-week long Basic Clerkships, including 1 week of Intersessions, 1 week of PRECEDE
Electives, including optional break
Advanced Clerkships</td><td>Break</td><td colspan="4">9-week long Basic Clerkships, including 1 week of Intersessions, 1 week of PRECEDE
Electives, including optional break
Advanced Clerkships</td><td>Break</td><td colspan="5">9-week long Basic Clerkships, including 1 week of Intersessions, 1 week of PRECEDE
Electives, including optional break
Advanced Clerkships</td></tr>
<tr><td colspan="14">Year 4</td></tr>
<tr><td colspan="10">8 months (August – March)</td><td>2 wks</td><td colspan="3">Graduation in May</td></tr>
<tr><td colspan="3">9-week long Basic Clerkships, including 1 week of Intersessions, 1 week of PRECEDE
Electives, including optional break
Advanced Clerkships</td><td>Break</td><td colspan="4">9-week long Basic Clerkships, including 1 week of Intersessions, 1 week of PRECEDE
Electives, including optional break
Advanced Clerkships</td><td>Break</td><td>TRIPLE</td><td colspan="3">Electives
Advanced Clerkships</td></tr>
</table>

* SC indicates scholarly concentration; PRECEDE, preclinical education exercise; TRIPLE, Transition to Residency and Preparation for Life.

in that area. The SC course seminars will be broadly grouped into topics such as basic science investigation, clinical investigation, public health and policy, the history of medicine, and ethics, humanities, and the healing arts. Each student will choose one of these SC seminars after completion of the SFM course and will continue in that area until the end of year two. Seminars will occur during intersessions, and structured mentorship opportunities for the school year and the summer will be provided to enrich the curriculum in the student's chosen area. To complete the SC course, each student must submit a mentored scholarly project. We anticipate that these experiences will give students an opportunity to enrich their learning in areas of their own choosing and will also foster independent learning, critical review of the literature, and excitement about an academic career.

After completing the GTS course and a four-week Transition to the Wards course that combines problem-based learning modules with practical information (e.g., interpretation of electrocardiograms, teamwork skills, and image interpretation), the students will embark on clinical clerkships that provide intense clinical experiences building on the CF course in year one and the LAC in years one and two. The Core Clinical Clerkships will begin with weeklong preclinical educational exercises that are specific to the core clerkship and that address systems-based practice, practice-based learning, core didactics, and issues that are specific to the local patient population or generally applicable to the broader society. After the Core Clinical Clerkships come the weeklong translational medicine intersessions, in which basic science and clinical faculty will jointly lead seminars focusing on the basic science implications of the clinical experiences that the students observed firsthand during their clerkships. In addition to emphasizing the scientific basis of medicine, these intersessions will reinforce rigorous thinking, lifelong learning, and the conceptual basis for patient individuality. This is an ideal time in which to reexcite students about translational research careers because they will have an immediate opportunity to reflect on how science can directly influence clinical care under the GTS paradigm. These intersessions will also provide another opportunity for the interaction of basic

science and clinical faculties in collaborative activities that may extend beyond the medical curriculum to the development of innovative research projects.

In addition to Core Clinical Clerkships, students will continue to have great flexibility to determine their elective rotations to prepare for residency. However, each student also must take an Advanced Clerkship in Chronic Care (e.g., geriatrics, physical medicine and rehabilitation, or palliative care) and an Advanced Clerkship in Intensive Care. These advanced clerkships will not only address the individual patient's clinical problems but will also focus more broadly on the societal and economic issues of chronic care and intensive care, respectively. This emphasis on the societal component of GTS within these subinternships illustrates for the student how the individual patient phenotype may affect the family (or community or society), and vice versa. Each student will also be required to complete a subinternship in medicine, pediatrics, obstetrics–gynecology, or surgery before graduating. Finally, just before graduation, all students will complete a capstone course, called Transition to Residency and Preparation for Life (TRIPLE). TRIPLE allows students to hone the knowledge and skills needed to tackle the practical, moral, ethical, and personal issues encountered by a resident physician and, more broadly, by a medical professional. Course material ranges from preparation to obtain Advanced Cardiac Life Support certification, to exercises in reflective writing after "adoption" of a patient, to guidance on stress management.

Key aspects of the GTS curriculum are its developmental progression and educational continuity.[27] Students will have experiences of greater sophistication and complexity as they progress through the four years within the GTS perspective. Concepts will be reinforced deliberately in a fashion that is predictable and within the context of the student's experiences. This integration is essential to a vertically oriented, systems-biology-based curriculum, so that students understand the relationship and interdependence of systems. Also built into the curriculum is the horizontal development of multidisciplinary biomedical and sociomedical topics such as neoplasia, imaging, therapeutics, ethics, safety, aging, public health, and pain (the full list of these "horizontal strands" is given above, in the seventh paragraph of the section titled "The Curriculum Reform—Process and Challenges"; also, see Table 2). By tracking these horizontal strands throughout the four-year curriculum, we will be able to ensure broad coverage of these important multidisciplinary topics at multiple points throughout the medical school experience, which means that the students will reencounter these topics even as their own sophistication and experience increase. We have established a strong central (nondepartmental) curriculum administration to monitor the vertical and horizontal content areas of the curriculum and to replace the traditional departmental organization of coursework.

By establishing the GTS perspective from the beginning of medical school, this curriculum will permit the student to rapidly incorporate new scientific discoveries into a coherent framework of understanding. The curriculum is also designed to highlight the dynamic state of our understanding of health and the need for further discovery, intellectual rigor, societal awareness, and lifelong learning.

How Will the GTS Curriculum Look Different?

Experienced clinicians have learned that every patient is different and that the

Table 2

Integration of Horizontal Strands in Years One and Two of the Johns Hopkins School of Medicine "Genes to Society" Curriculum

	Years One and Two	
Horizontal strands	Scientific foundations, clinical foundations, and foundations of public health	"Genes to Society" curriculum, longitudinal clerkship, transition to the wards, and scholarly concentrations
Genomics/proteomics	Introduction	Genetic components of each organ system
Imaging	Human anatomy	Review of organ-specific anatomy
Informatics		Introduction to EMRs*
Molecular embryology	Developmental biology	Reproduction
Pathology	Anatomy	Virtual microscopy
Pharmacology	Pharmacology	Drug interactions, pain pharmacology
Human development		Aging, fetal development
Pain	Recognizing a patient in pain	Pain assessment and emergencies
Patient safety		Patient safety
Professionalism	Ethics	Working in outpatient settings
Epidemiology	Biostatistics, introduction to epidemiology	Epidemiology of pain
Nutrition	Health promotion	Obesity and satiety
Communication	Interviewing	History and physical examination
Cultural competence	Health disparities	
Public health	Disease prevention	Global health, disaster medicine
Clinical reasoning		Evidence-based medicine

* EMR indicates electronic medical records.

"classic case" is merely a pedagogical construct. In the face of the rapidly increasing scientific evidence of extensive variation, the question for medical education is, how do we transition to teaching individuality? The GTS perspective, with its emphasis on individuality, provides a conceptual framework for thinking about medicine. Throughout the four years of medical school, students will learn tangible examples of these concepts to reinforce this context. For example, during the myocardial infarction component of the cardiovascular section of the GTS course, students in team learning venues can simultaneously study and share what they have learned about cases of acute myocardial infarction in young people with monogenic genetic disorders of lipid metabolism as compared with acute myocardial infarction in older people with multifactorial risks (e.g., genetic predisposition, diabetes, obesity, inflammation, calcific arterial disease, and cigarette smoking). Blended throughout this section of the course will be an understanding of the interplay between individual characteristics and environmental experiences that translate into angina, plaque rupture, ischemia, remodeling, and repair. Our definition of environmental factors is broad, and it encompasses sociocultural variables, disease screening, public health measures, and health care access and utilization issues. Moreover, in the translational medicine intersession that follows the Core Medicine Clerkship, students will have an opportunity to reanalyze a patient with myocardial infarction from the perspective of alterations in ion channel function, mitochondrial energetics, platelet receptor binding, and so on. These seminars, jointly led by clinicians and basic scientists, will focus on the interface between basic biology and clinical experiences. The dynamic nature of medical knowledge will be reinforced during these intersessions as students revisit, after their Core Clinical Clerkship, topics they considered one to two years earlier in their GTS course, and they will have the opportunity to integrate their background knowledge with firsthand patient experience and review of the current literature. These lessons are important demonstrations of the need for lifelong learning and continuing medical education.

Challenges for the Future

The issue of overall curricular assessment and evaluation is an important challenge. We are currently collecting data on student experience, graduate outcomes, board scores, and career satisfaction that will be used in comparisons with students from the pre-GTS era. However, we do not yet have an adequate metric to answer the often-asked question, "How will we know if the GTS curriculum is better than our old curriculum?" We currently are seeking a method by which to determine whether the educational experience has allowed the graduate to integrate information spanning the range from the molecule to society in such a way as to improve health or advance biomedical science during the course of a career. One potential avenue involves "concept mapping" as a tool for cognitive task analysis.[28] Concept mapping is a validated tool of knowledge elicitation and knowledge representation, wherein a team of students could build a relational map of the most relevant concepts in explaining a patient's phenotype by using GTS concepts.[28,29,30] Faculty experts from different specialties could be invited to critique these maps for granularity, comprehensiveness, and relevance to the integration of the knowledge needed for clinical care and communication with the patient. We would hope to find a developmental progression, with students showing greater and greater sophistication in applying GTS concepts as they progress through medical school.

How the current economic downturn will affect the new curriculum is not clear. To date, the dean of the JHU School of Medicine has funded the faculty time necessary to plan the new curriculum, and there are no plans to cut those funds or to decrease the current faculty support for teaching. One of the several committees that spun off from curriculum reform examined the valuation of medical education and developed a valuation methodology. This committee noted that valuation of education is measured not only with money but also with faculty recognition and promotion and with departmental recognition during the annual review by the dean. A methodology was developed to interchange these types of valuations—personal, departmental, and financial.

The need for a certain level of funds is inescapable during curriculum reform. We argue that minor tinkering with an existing curriculum is less likely to be perceived as adding value to an institution than is wholesale reform. At the same time, those responsible for education must constantly strive to diversify the funding base beyond tuition—through grants, consulting contracts, continuing education courses, etc.—while paying scrupulous attention to the risks of conflict of interest or dilution of the institutional mission.

Summary

The goal of medical school—namely, to educate students in preparation for fulfilling careers in clinical care, investigation, education, and leadership—has not changed; however, to reach this goal, the next generation of physicians will require a new conceptual foundation of health and disease that focuses on individual characteristics and that explores how they interact with accrued environmental experiences. It is interesting that this emphasis on individuality will require physicians to know and communicate with their patients in ways that are improved over those currently in use; that fact provides the biological rationale for a productive patient–physician interaction.[8] The focus on systems biology imbues students with an appreciation of the complexity and importance of the relationship among health, risk, prevention, disease, and therapy. Hood and colleagues[31] called this approach "P4 medicine," with "P4" representing predictive, preventive, personalized, and participatory medicine. Our GTS curriculum proposes a way of teaching P4 medicine. A recent report from the Macy Foundation proposed that medical school curricula become more aligned with societal needs and expectations.[32] It is the goal of the JHU School of Medicine to educate future physicians and scientists by using the GTS conceptual model of health and disease that takes into account the ongoing revolutions in scientific discovery, public accountability, and societal health.

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References

1 Flexner A. Medical Education in the United States and Canada: A Report to the Carnegie Foundation for the Advancement of Teaching. Bulletin No. 4. Boston, Mass: Updyke; 1910.
2 Cooke M, Irby DM, Sullivan W, Ludmerer K. American medical education 100 years after the Flexner report. N Engl J Med. 2006;355: 1339–1344.
3 Kleinman A, Eisenberg L, Good B. Culture, illness, and care clinical lessons from anthropologic and cross-cultural research. Ann Intern Med. 1978;88:251–258.
4 Choudhry NK, Fletcher RH, Soumerai SB. Systematic review: The relationship between clinical experience and quality of health care. Ann Intern Med. 2005;142:260–273.
5 Feero WG, Guttmacher AE, Collins FS. The genome gets personal—almost. JAMA. 2008; 299:1351–1352.
6 Department of Health and Human Services. Realizing the Promise of Pharmacogenomics: Opportunities and Challenges. Report of the Secretary's Advisory Committee on Genetics, Health, and Society. Available at: http://oba.od.nih.gov/oba/SACGHS/reports/SACGHS_PGx_report.pdf. Accessed November 21, 2009.
7 Childs B. Genetic Medicine: A Logic of Disease. Baltimore, Md: Johns Hopkins University Press; 1999.
8 Childs B, Wiener C, Valle D. A science of the individual: Implications for a medical school curriculum. Annu Rev Hum Genet. 2005;6: 313–330.
9 Scriver C. The PAH gene, phenylketonuria, and a paradigm shift. Hum Mutat. 2007;9: 831–845.
10 Levy S, Sutton G, Feuk L, et al. The diploid genome of an individual human. PLoS Biol. 2007;5:e254.
11 Wheeler DA, Srinivasan M, Egholm M, et al. The complete genome of an individual by massively parallel DNA sequencing. Nature. 2008;452:872–876.
12 Wang J, Wang W, Li R, et al. The diploid genome sequence of an Asian individual. Nature. 2008;456:60–65.
13 Anderson JL, Horne BD, Stevens SM, et al. Randomized trial of genotype-guided versus standard warfarin dosing in patients initiating oral anticoagulation. Circulation. 2007;116: 2563–2570.
14 Sebat J, Lakshmi B, Troge J, et al. Large-scale copy number polymorphism in the human genome. Science. 2004;305:525–528.
15 Redon R, Ishikawa S, Fitch KR, et al. Global variation in copy number in the human genome. Nature. 2006;444:444–454.
16 Barnes KC. A review of the genetic epidemiology of resistance to parasitic disease and atopic asthma: Common variants for common phenotypes? Curr Opin Allergy Clin Immunol. 2005;5:379–385.
17 Manolio TA, Brooks LD, Collins FS. A HapMap harvest of insights into the genetics of common disease. J Clin Invest. 2008;118: 1590–1605.
18 Altshuler D, Daly MJ, Lander ES. Genetic mapping in human disease. Science. 2008; 322:881–888.
19 Wiley HS. Systems Biology: Beyond the Buzz. The Scientist. 2006;20:52.
20 Schadt EE, Sachs A, Friend S. Embracing complexity, inching closer to reality. Sci STKE. 2005;295:pe40.
21 Hartwell LH, Hopfield JJ, Leibler S, Murray AW. From molecular to modular cell biology. Nature. 1999;420(6761 suppl):C47–C52.
22 DeAngelis C, ed. The Johns Hopkins University School of Medicine Curriculum for the Twenty-First Century. Baltimore, Md: Johns Hopkins University Press; 2000.
23 Bland CJ, Starnaman S, Wersal L, et al. Curricular change in medical schools: How to succeed. Acad Med. 2000;75:575–594.
24 Kern D, Thomas P, Howard D, Bass E, eds. Curriculum Development for Medical Education: A Six-Step Approach. Baltimore, Md: Johns Hopkins University Press; 1998.
25 Ashar B, Levine R, Magaziner J, Shochet R, Wright S. An association between paying physician teachers for their teaching efforts and improved educational experiences for learners. J Gen Intern Med. 2007;22:1393–1397.
26 Zerhouni E. The NIH Roadmap. Science. 2003;302:63–64, 72.
27 Hirsh DA, Ogur B, Thibault GE, Cox M. Continuity as an organizing principle for clinical education reform. N Engl J Med. 2007;356:858–866.
28 Crandall B, Klein G, Hoffman RR, eds. Working Minds—A Practitioner's Guide to Cognitive Task Analysis. Cambridge, Mass: MIT Press; 2006.
29 Srinivasan M, McElvany M, Shay J, et al. Measuring knowledge structure: Reliability of concept mapping assessment in medical education. Acad Med. 2008;83:1196–1203.
30 West DC, Pomeroy JR, Park JK, et al. Critical thinking in graduate medical education: A role for concept mapping assessment? JAMA. 2000;284:1105–1110.
31 Hood L, Heath JR, Phelps ME, Lin B. Systems biology and new technologies enable predictive and preventative medicine. Science. 2004;306:640–643.
32 Cohen JJ. Chairman's summary of the conference. In: Hager M, ed. Revisiting the Medical School Mission at a Time of Expansion, 2008. Charleston, SC: Josiah Macy, Jr. Foundation; 2008.

Did You Know?

In 1848, the University of Maryland School of Medicine became the first American medical school to make anatomical dissection compulsory.

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