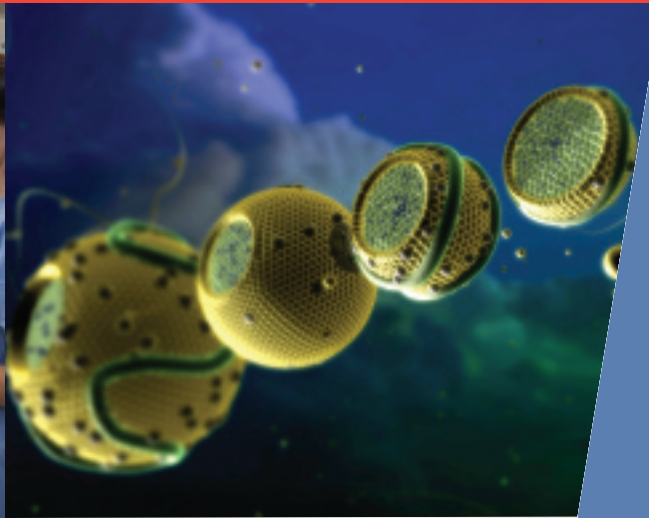


HHMI



Tomorrow's Doctors, Tomorrow's Cures®

Scientific Foundations for Future Physicians



2009



Report of the AAMC-HHMI Committee

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Introduction

In recent years, members of the higher education community, individually and through several expert panel reports,^{1,2,3,4,5} have raised concerns about the science content in the current premedical and medical education curricula. These concerns are especially important given the increasingly rapid rate at which new knowledge revises our understanding of the sciences fundamental to medicine. There is widespread agreement that it is important to: (1) educate future physicians to be inquisitive; (2) help them build a strong scientific foundation for future medical practice; and (3) equip them with the knowledge, skills, and habits of mind to integrate new scientific discovery into their medical practice throughout their professional lives and to share this knowledge with patients and other health care professionals.

With these issues in mind, the Association of American Medical Colleges (AAMC) and the Howard Hughes Medical Institute (HHMI) formed a partnership to examine the natural science competencies that a graduating physician needs to practice science-based medicine effectively with the goal of achieving greater synergy and efficiency in the continuum of premedical and medical education.

The AAMC and HHMI convened a group of scientists, physicians, and science educators from small colleges, large universities, and medical schools around the United States to determine the most important scientific competencies required of students graduating from college prior to matriculating into medical school as well as the scientific competencies required of medical school graduates as they enter postgraduate training. The group, known as the Scientific Foundations for Future Physicians (SFFP) Committee, was charged to:

- Consider the means and consequences of establishing the concept of “science competency” (learner performance), rather than academic courses, as the basis for assessing the preparation of medical school applicants and the proficiency of medical school graduates.
- Recommend the specific competencies in the sciences fundamental to medicine that all medical students should demonstrate before receiving the M.D. degree.
- Identify the scientific competencies that premedical students should demonstrate before entry into medical school. Emphasis should be on defined areas of knowledge, scientific concepts, and skills rather than on specific courses or disciplines.
- Propose strategies for achieving the recommended science competencies across the educational experience of students pursuing the M.D. degree, while recognizing that the competencies will continue to evolve.
- Recommend approaches to update the list of science competencies as knowledge, learner needs, and medical practice change.

Issues of Concern and Goals

This report stems largely from the concern that premedical course requirements have been static for decades and may not accurately reflect the essential competencies every entering medical student must have mastered, today and in the future. The competencies for premedical education need to be broad and compatible with a strong liberal arts education. The work of the committee is based on the premise that the undergraduate years are not and should not be aimed only at students preparing for professional school. Instead, the undergraduate years should be devoted to creative engagement in the elements of a broad, intellectually expansive liberal arts education. Therefore, the time commitment for achieving required scientific competencies should not be so burdensome that the medical school candidate would be limited to the study of science, with little time available to pursue other academically challenging scholarly avenues that are also the foundation of intellectual growth.

One goal of this project is to provide greater flexibility in the premedical curriculum that would permit undergraduate institutions to develop more interdisciplinary and integrative science courses, as recommended in the *BIO 2010* report.⁶ By focusing on scientific competencies rather than courses, undergraduate institutions will have more freedom to develop novel courses to achieve the desired competencies without increasing the total number of instructional hours in the sciences in the face of continuing increases in medically relevant scientific knowledge. Achieving economies of time spent on science instruction would be facilitated by breaking down barriers among departments and fostering interdisciplinary approaches to science education. Indeed, the need for increased scientific rigor and its relevance to human biology is most likely to be met by more interdisciplinary courses.

Competencies may be achieved in different ways by a variety of courses or educational experiences. This should release the student from specific course requirements, but it will require each institution to identify the instructional means by which the necessary competencies can be gained. The committee recognizes that some colleges and universities have already implemented many of the report's recommendations and other institutions are beginning to develop a competency-based approach to learning as well as an integrated curriculum.

The focus on competencies, rather than courses, for admission to medical school will require a new approach to assessment, uncoupling specified prerequisite courses from the desired outcomes of premedical education. Further, assessment of the newly defined scientific competencies must be credibly and reliably accomplished by the Medical College Admission Test (MCAT®) exam.

There is also widespread concern^{7,8} that the basic science content in the medical school curriculum has not kept pace with the expanding scientific knowledge base of medicine and fails to reflect accurately the importance of the sciences in the practice of medicine. There is a perception that while there have been many changes in how science is taught in the first two years of medical school, little has changed to optimally integrate the sciences into the third and fourth years of medical school education.⁹ Moreover, the integration of clinical education and basic science often lacks sufficient emphasis on fundamental scientific principles that are key to lifelong learning and biomedical scientific literacy. Understanding these principles is essential to empower physicians to continue to comprehend their own disciplinary literature and to evaluate critically claims of therapeutic effectiveness and safety throughout their active careers.

The desired outcome of the medical education process should be scientifically inquisitive and compassionate physicians who have the motivation, tools, and knowledge to find the necessary information to provide the best and most scientifically sound care for their patients. As such, the medical school curriculum should be integrated across disciplines and repeatedly emphasize the importance and relevance of the sciences basic to medicine.

As with undergraduate education, the committee recognizes the value of improving integration in the teaching of the basic physical, chemical, mathematical, and biological sciences in medical education. Organizing educational programs according to departmental priorities is a long-standing tradition in both undergraduate and professional education, but some institutions have begun to develop their educational program through an integrated, nondepartmental approach, and it is this approach the committee supports in the report. Integration of teaching of the basic sciences in medical schools requires that the schools develop new approaches to assess the competencies appropriately. In turn, the medical school competencies should be accurately reflected in the examinations used for licensure of physicians.

Physicians will increasingly provide care in the context of coordinated multidisciplinary health care delivery teams and must demonstrate that they can work with such teams to make effective use of the group's collective knowledge and experience. Physicians should possess a deep understanding of the fundamental biomedical scientific principles needed to deal with the unexpected; they should not rely solely on algorithm-based practice.

Although not addressed in this report, there is also the need to assess the behavioral and social science foundations for future physicians. At the time of this report's publication, a separate initiative is underway under the auspices of the AAMC.

Defining Competency

The shift from defining required courses to articulating competencies is becoming increasingly widespread in education.¹⁰ In a seminal article in 2002,¹¹ Hundert and Epstein reviewed work done on achieving competency and established a definition of competency that is widely accepted in medical education: “Competency is the habitual and judicious use of communication, knowledge, technical skills, clinical reasoning, emotions, values, and reflection in daily practice for the benefit of the individual and the community being served.” Competence develops over time, and as competence is nurtured by reflection on experiences, it becomes a habit. Previously, in an article in the *Journal of the American Medical Association (JAMA)* in 1999, Epstein wrote about the concept of mindfulness and its importance in developing competence.¹² He argues that competence depends on habits of mind that allow the practitioner to be attentive, curious, self-aware, and willing to recognize and correct errors. Competencies are specific learned abilities that the practitioner has adopted as a consequence of his or her education.

Recognizing that the SFFP initiative focuses not only on scientific competencies needed for medical practice but also on those that equip an individual to learn medicine, the committee defines a competency as the knowledge, skill, or attitude that enables an individual to learn and perform in medical practice and to meet or exceed the standards of the profession. Notwithstanding the focus of this initiative, the committee believes that the specific guidance and recommendations presented for undergraduate competencies are not limited to the student engaged in premedical education, but are also valuable for the subsequent study of any career in the health or life sciences.

Overarching Principles

To guide their deliberations to define competencies, panel members developed the following overarching principles:

1. The practice of medicine requires grounding in scientific principles and knowledge, as well as understanding how current medical knowledge is scientifically justified, and how that knowledge evolves.
2. The principles that underlie biological complexity, genetic diversity, interactions of systems within the body, human development, and influence of the environment guide our understanding of human health, and the diagnosis and treatment of human disease.
3. Curiosity, skepticism, objectivity, and the use of scientific reasoning are fundamental to the practice of medicine. These attributes should permeate the entire medical education continuum.
4. Modern medicine requires the ability to synthesize information and collaborate across disciplines.

5. Effective clinical problem solving and the ability to evaluate competing claims in the medical literature and by those in medical industries depend on the acquisition, understanding, and application of scientific knowledge and scientific reasoning based on evidence.
6. It is essential not only to read the medical and scientific literature of one's discipline, but to examine it critically to achieve lifelong learning. These activities require knowledge and skills in critical analysis, statistical inference, and experimental design.
7. Medical professionals should demonstrate strong ethical principles and be able to recognize and manage potential conflicts of interest.
8. Application of scientific knowledge in medicine requires attention both to the patient as an individual and in a social context.
9. The effective practice of medicine recognizes that the biology of individual patients is complex and variable and is influenced by genetic, social, and environmental factors.
10. Decision making in medical practice involves uncertainties and risks.
11. Scientific matters can and should be communicated clearly to patients and the public, taking into account the level of scientific literacy of these audiences and understanding the intellectual and emotional responses to medical diagnoses and therapies.

For example, physicians should be able to explain to patients:

- the complexity and variability of the human body to help them appreciate that there is no single approach to the prevention, diagnosis, and management of disease;
- the influence of genetic, lifestyle, and environmental factors in health and disease, as well as the heritability of genetic factors;
- in appropriate terms, the technologies for diagnosis and treatment of disease, their relative risks and benefits, and the advantages and disadvantages of alternative choices;
- in appropriate terms, the rationale for treatment strategies, including lifestyle changes as well as pharmacological interventions, how the drugs work, their possible interactions with other drugs, their risks and benefits, and alternatives, both pharmacological and nonpharmacological; and
- how the brain and other organ systems interact to mediate behavior throughout the lifespan in health and in disease.

Specific communication skills that students should master and apply to the fields of medicine and scientific inquiry include the ability to:

- write logically and with clarity and style about important questions across disciplines;
- articulate persuasively, both orally and in writing, focused, sophisticated, and credible thesis arguments;
- be able to use the methodologies that particular disciplines apply for understanding and communicating results effectively;
- approach evidence with probity and intellectual independence; and
- use source material appropriately with scrupulous and rigorous attribution.

Medical School Objective Project (MSOP) Expert Panel on the Behavioral and Social Sciences

The Medical School Objectives Project (MSOP) is an AAMC initiative, begun in 1998, designed to reach general consensus within the medical education community on the skills, attitudes, and knowledge that all graduating medical students should possess. A new MSOP expert panel has been convened to deliberate and offer recommendations on the learning objectives and educational strategies for the behavioral and social sciences for all medical students. The panel is specifically asked to address two fundamental questions:

- What should medical students learn about the behavioral and social sciences (learning objectives), considering what is most important for entry to medical school and to learn during medical school?
- What kind of educational experiences would allow students to achieve those learning objectives?

In conducting its deliberations, the committee will consider the recommendations of several reports, including the SFFP project, as well as other ongoing initiatives, such as the MCAT Review. Throughout the panel's deliberations there will be regular updates about the content of the report and opportunities for input from the medical education community. The panel is expected to complete its report by late 2010. For more information about the MSOP initiative, visit www.aamc.org/msop.

How This Report Came to Be

The committee met five times. Most meetings included at least one non-panel guest to provide broad perspectives on the work of the committee. The bulk of the meeting time was spent with committee members working in small groups of 5–6 to define the key areas on which to focus and the competencies to accompany each topic area. Committee members also worked in subgroups to develop examples. Committee meetings were enriched with vigorous debate, and lively conversations continued between meetings via conference calls and e-mail.

The first eight competencies focus on the sciences basic to medicine that students must gain by the completion of medical school. Using the competencies and learning objectives defined for medicine, committee members then turned their efforts to defining eight competencies and corresponding learning objectives for premedical science education. It was impractical to try to align each competency and objective defined for undergraduate education with one of the eight competencies defined for medicine because the competencies are, by design, not specific to a single domain.

In what follows, the committee first presents those competencies deemed important for medical school education, followed by those identified for entering medical students. The competencies and their corresponding learning objectives are accompanied by examples of a few ways the competency could be included in an educational program. The competencies are general, by definition and design, and the learning objectives and examples are not in any sense intended to be prescriptive or encyclopedic. Rather, they are intended to give a flavor of the depth and specificity of the competencies. The document that follows is presented as a blueprint or framework with which educators can build educational programs for the undergraduate student interested in medicine as a career and for the student studying medicine.

Medical School Competencies

Competency M1

Apply knowledge of molecular, biochemical, cellular, and systems-level mechanisms that maintain homeostasis, and of the dysregulation of these mechanisms, to the prevention, diagnosis, and management of disease.

Learning Objectives:

1. Apply knowledge of biological systems and their interactions to explain how the human body functions in health and disease.

Examples:

- Explain how a decrease in cardiac contractility leads to sodium and water retention, edema, and hypotonicity.
- Define the mechanisms by which liver failure results in portal hypertension, varices, ascites, and hypoalbuminemia, and how these interrelate.

2. Use the principles of feedback control to explain how specific homeostatic and reproductive systems maintain the internal environment and identify (1) how perturbations in these systems may result in disease and (2) how homeostasis may be changed by disease.

Examples:

- Explain how blood loss results in changes in hemodynamics and red blood cell production.
- Explain how the peripheral nervous system fails in autonomic neuropathy.
- Explain how lung disease results in hyperventilation.

3. Apply knowledge of the atomic and molecular characteristics of biological constituents to predict normal and pathological molecular function.

Examples:

- Explain how in severe myoclonic epilepsy of infancy a mutation in the Na(V) 1.1 channel results in a shift of the voltage activation curve.
- Explain how numerous mutations in the gene for acid beta-glucosidase give rise to loss of protein function and their relationship to the genetics and pathology of Gaucher disease.
- Explain the mechanism of how active site directed drugs, such as aspirin and other non-steroidal anti-inflammatory drugs (NSAIDs), act on cyclooxygenase to inhibit enzyme activity.

4. Explain how the regulation of major biochemical energy production pathways and the synthesis/degradation of macromolecules function to maintain health and identify major forms of dysregulation in disease.

Examples:

- Explain how lack of insulin results in the metabolic consequences of diabetes mellitus, such as hyperglycemia and ketoacidosis.
- Explain how abnormalities in liver metabolism of cholesterol result in hypercholesterolemia.
- Apply knowledge of the regulation of pathways for energy production to the production of lactic acidosis during hypoxia.
- Explain how urea metabolism and its abnormal regulation in renal and hepatic disease can result in uremia.

5. Explain the major mechanisms of intra- and intercellular communication and their role in health and disease states.

Examples:

- Explain the differing effects of pituitary and adrenal lesions on glucocorticoid and mineralocorticoid function.
- Describe the effects of abnormalities in the mineralocorticoid receptor or 11-beta hydroxysteroid dehydrogenase on salt metabolism.
- Describe the effects of mutations in the androgen receptor on transcriptional regulation and sexual differentiation.
- Explain the effects of insulin on glucose and lipid metabolism, and the role of this pathway in the pathogenesis of types I and II diabetes mellitus.
- Explain the autocrine and paracrine actions of prostaglandins on cells.

6. Apply an understanding of the morphological and biochemical events that occur when somatic or germ cells divide, and the mechanisms that regulate cell division and cell death, to explain normal and abnormal growth and development.

Examples:

- Explain how abnormalities in regulation of cell division and cell death result in cancer.
- Describe the process by which the paddle-shaped hand- and foot-plates of the embryo develop separate digits, and identify the condition that results when the molecular and cellular events of this process are blocked.

- Describe the serial processes of partitioning the primordial atrium and its relationship to fetal and postnatal blood flow.
7. Identify and describe the common and unique microscopic and three-dimensional macroscopic structures of macromolecules, cells, tissues, organs, systems, and compartments that lead to their unique and integrated function from fertilization through senescence to explain how perturbations contribute to disease.

Examples:

- Explain the structural and functional consequences of cancer treatments targeting rapidly dividing cells on normal cells having a short lifespan, such as those in the alimentary system.
 - Explain how the interaction of endothelial cells and podocytes accomplish glomerular filtration and how podocyte abnormality leads to the nephrotic syndrome.
 - Explain the developmental events leading from polyneuronal innervation to the innervation of skeletal muscle fibers by individual spinal motor neurons.
8. Predict the consequences of structural variability and damage or loss of tissues and organs due to maldevelopment, trauma, disease, and aging.

Examples:

- Predict how genetic mutations in the microfibril genes result in abnormal connective tissue that may result in aortic aneurysm, joint laxity, and skeletal deformities (i.e., Marfan syndrome).
- Predict the musculoskeletal consequences that result from a unilateral failure of sclerotomal mesenchymal cells to form the primordial half of a vertebra.
- Predict the pre- and postnatal consequences of failure of the left pleuroperitoneal fold to form a complete pleuroperitoneal membrane, and explain why such a failure on the left side is of greater significance than the same failure on the right side.
- Explain the anatomical changes in tetralogy of Fallot and how abnormal cardiovascular development leads to this abnormality and its resulting effect on the pulmonary circulation.

9. Apply principles of information processing at the molecular, cellular, and integrated nervous system level and understanding of sensation, perception, decision making, action, and cognition to explain behavior in health and disease.

Examples:

- Explain how the degeneration of dopaminergic neurons in Parkinson's disease impairs reinforcement learning and decision making for initiation of appropriate actions.
- Explain how misalignment (strabismus) of the two eyes impairs the computation of visual target distance (depth perception) by the neurons of the visual cortex.

Competency M2

Apply major principles of physics and chemistry to explain normal biology, the pathobiology of significant diseases, and the mechanism of action of major technologies used in the prevention, diagnosis, and treatment of disease.

Learning Objectives:

1. Apply the principles of physics and chemistry, such as mass flow, transport, electricity, biomechanics, and signal detection and processing, to the specialized functions of membranes, cells, tissues, organs, and the human organism, and recognize how perturbations contribute to disease.

Examples:

- Apply knowledge of diffusion to gas exchange in the lung and to water and electrolyte exchange in the kidney.
- Describe the role of signal processing in sensory systems and its significance for disease.
- Diagnose blood disorders using knowledge of flow resistance and viscosity.
- Explain to a patient how and why albumin is important in regulating blood volume by maintaining the osmotic pressure of the blood compartment.

2. Apply the principles of physics and chemistry to explain the risks, limitations, and appropriate use of diagnostic and therapeutic technologies.

Examples:

- Describe the function of radioactive tracers for diagnosis of disease.
- Contrast the resolution expected from transesophageal versus transthoracic echocardiography using physical principles.
- Describe the connection between NMR techniques to identify chemical compounds and MRI as a diagnostic tool.

Competency M3

Use the principles of genetic transmission, molecular biology of the human genome, and population genetics to infer and calculate risk of disease, to institute an action plan to mitigate this risk, to obtain and interpret family history and ancestry data, to order genetic tests, to guide therapeutic decision making, and to assess patient risk.

Learning Objectives:

1. Describe the functional elements in the human genome, their evolutionary origins, their interactions, and the consequences of genetic and epigenetic changes on adaptation and health.

Examples:

- Explain how nonhomologous recombination accounts for microdeletion/duplication syndromes, such as velo-cardio-facial syndrome.
 - Explain how microarray analysis of gene expression can be used to predict responsiveness of different tumors to specific chemotherapy regimens.
 - Explain the role of micro RNAs in gene regulation.
 - Explain the molecular basis of disorders resulting from aberrant genomic imprinting, such as Prader-Willi and Angelman syndromes.
2. Describe the major forms and frequencies of genetic variation and their consequences on health in different human populations.

Examples:

- Recognize the indications for genetic testing and interpret the results to determine risk of rare or common diseases.

- Provide counseling to individuals on the risk of carrier status based on ancestry.
 - Explain the role of germline or somatic mutation in pathogenesis.
 - Explain how phenomena of balanced polymorphism and the founder effect account for different frequencies of disease in different populations.
3. Explain how variation at the gene level alters the chemical and physical properties of biological systems, and how this, in turn, influences health.

Examples:

- Develop an appropriate strategy to diagnose and treat individuals with inborn errors of metabolism.
 - Customize cancer therapy to genetically defined subtypes of disease.
 - Explain how phenotypic variability results from distinct mutations in a specific gene, such as different type I collagen mutations in osteogenesis imperfecta.
4. Describe the various patterns of genetic transmission within families and implications for the health of family members.

Examples:

- Recognize indications for genetic testing based on information obtained from a pedigree.
 - Calculate the risk of recurrence of a genetic disorder in a family using principles of transmission genetics.
 - Describe the different forms of genetic tests (diagnostic, prenatal, predictive, predispositional).
5. Explain how genetic and environmental factors interact to produce phenotypes and provide the basis for individual variation in response to toxic, pharmacological, or other exposures.

Examples:

- Modify choice of drug and/or dosage based on results of pharmacogenetic testing.
- Explain how environmental and stochastic factors contribute to the phenomenon of incomplete penetrance.
- Explain why individuals differ in their sensitivity to environmental factors, such as ethanol.

Competency M4

Apply the principles of the cellular and molecular basis of immune and nonimmune host defense mechanisms in health and disease to determine the etiology of disease, identify preventive measures, and predict response to therapies.

Learning Objectives:

1. Apply knowledge of the generation of immunological diversity and specificity to the diagnosis and treatment of disease.

Examples:

- Describe the role of somatic gene rearrangements and clonality to the diversity and specificity of immune responses (e.g., polio, malaria).
- Explain how clonality determination can help in diagnosing lymphoid neoplasms.
- Explain the rationale for the suite of childhood immunizations.

2. Apply knowledge of the mechanisms for distinction between self and nonself (tolerance and immune surveillance) to the maintenance of health, autoimmunity, and transplant rejection.

Examples:

- Explain the importance of having an HLA matched renal transplant.
- Relate the occurrence of HLA B27 to ankylosing spondylitis, and Reiter's syndrome.
- Explain the two mechanisms of self tolerance in T cells (clonal deletion and peripheral regulation by T-reg cells) and the impact of the failure of these systems on the occurrence of autoimmunity, as in lupus and failure to eradicate cancers.
- Explain how the cells of the innate immune system can recognize a large number of pathogens by pattern recognition receptors whereas the adaptive immune systems use highly specialized receptors for non-self antigens, and the impact this has on how host defense systems are organized.

3. Apply knowledge of the molecular basis for immune cell development to diagnose and treat immune deficiencies.

Examples:

- Explain how the differentiation of hematopoietic stem cells into distinct cell types and their subclasses in the immune system allows for a coordinated host defense against pathogens (e.g., Ebola, hepatitis A and B).
- Relate the interruption of lymphoid differentiation to specific immune deficiencies (e.g., how mutations in the common gamma chain of cytokine receptors lead to severe combined immune deficiency).

4. Apply knowledge of the mechanisms utilized to defend against intracellular or extracellular microbes to the development of immunological prevention or treatment.

Examples:

- Explain why induction of antibody response is effective in preventing pneumococcal pneumonia but not pulmonary tuberculosis.
- Explain why it has been so difficult to develop a vaccine against HIV and malaria and why the influenza and polio vaccines are effective.
- Identify genetic, environmental, and lifestyle factors that increase patient disease risks and recommend prevention strategies.

Competency M5

Apply the mechanisms of general and disease-specific pathological processes in health and disease to the prevention, diagnosis, management, and prognosis of critical human disorders.

Learning Objectives:

1. Apply knowledge of cellular responses to injury, and the underlying etiology, biochemical and molecular alterations, to assess therapeutic interventions.

Examples:

- Explain how free radicals are formed and removed from cells and conditions under which free radicals can benefit the body (e.g., free radical-mediated injury to microbes in phagocytes) or cause injury to tissues (as in reperfusion injury in myocardial infarction).

- Relate the susceptibility of different cell types (renal tubule cells, hepatocytes, neurons) to the effects of anoxic injury caused by vascular compromise.
 - Relate the occurrences of misfolded proteins to the causation of human diseases (e.g., Alzheimer's disease) and what therapeutic interventions might prevent the harmful effects of misfolded proteins.
2. Apply knowledge of the vascular and leukocyte responses of inflammation and their cellular and soluble mediators to the causation, resolution, prevention, and targeted therapy of tissue injury.

Examples:

- Explain the role that arachadonic acid-derived mediators play in various steps of acute inflammation and how the inflammatory process can be moderated by use of specific inhibitors of the involved mediators.
- Exemplify in the context of specific diseases the beneficial effects of neutralizing (e.g., anti-TNF in rheumatoid arthritis) or enhancing (e.g., stem-cell mobilization with GM-CSF) inflammatory mediators.
- Compare and contrast the beneficial effects of regulated functions of the inflammatory response (e.g., the elimination of infectious agents) with the adverse consequences of their unregulated activation (e.g., sepsis).

MR5: 5th Comprehensive Review of the MCAT Exam

In the fall of 2008, the AAMC began a comprehensive review of the Medical College Admission Test (MCAT®). A 21-member committee was appointed by AAMC to conduct the review. The committee is charged with recommending changes that are likely to increase the MCAT exam's value to medical school admissions committees. In conducting their review, committee members will consider recent calls for new information about applicants' mastery of natural science content; behavioral and social sciences and humanities content; and professional competencies like cultural competence, communication skills, and professionalism. MR5 committee members are seeking input on the new exam at meetings and conference sessions, through surveys and other information-gathering activities, and from experts working on related issues. For example, the SFFP project will inform the deliberations of the MR5 committee, along with other initiatives, including the AAMC's Holistic Review Project and AAMC's Medical School Objectives Project for the Behavioral and Social Sciences. A new test will be introduced no earlier than 2013. For additional information, go to www.aamc.org/mr5.

3. Apply knowledge of the interplay of platelets, vascular endothelium, leukocytes, and coagulation factors in maintaining fluidity of blood, formation of thrombi, and causation of atherosclerosis to the prevention and diagnosis of thrombosis and atherosclerosis in various vascular beds, and the selection of therapeutic responses.

Examples:

- Define the regulatory circuits that allow endothelial cells to maintain the flow of fluid blood in health and trigger thrombosis following vascular injury, and mechanisms of action of the therapeutic agents that have been developed on the basis of these functions.
 - Explain the key steps and mediators in the evolution of atherosclerosis and how the process can be interrupted or prevented by selective targeting of various steps.
4. Apply knowledge of the molecular basis of neoplasia to an understanding of the biological behavior, morphologic appearance, classification, diagnosis, prognosis, and targeted therapy of specific neoplasms.

Examples:

- Explain the action of oncogenes in the context of normal growth factor-initiated signal transduction and how this information can be utilized for treatment of cancers (e.g., antibodies to EGFR in breast cancer, inhibition of tyrosine kinases in leukemias).
- Compare and contrast the actions of genes that promote cell growth in cancers with those that inhibit cell death and explain how this information influences the choice of therapeutic agents (e.g., Nodular B cell lymphomas and Large Cell B cell lymphomas).
- Give examples of the dependence of cancers on stromal elements and explain how this information can be used to treat cancers (e.g., anti-angiogenesis, matrix metalloproteinase inhibitors).

Competency M6

Apply principles of the biology of microorganisms in normal physiology and disease to explain the etiology of disease, identify preventive measures, and predict response to therapies.

Learning Objectives:

1. Apply the principles of host–pathogen and pathogen–population interactions and knowledge of pathogen structure, genomics, life-cycle, transmission, natural history, and pathogenesis to the prevention, diagnosis, and treatment of infectious disease.

Examples:

- Apply knowledge of plasmodium life cycle and pathogenesis to the behavioral (bed nets) and chemical (mefloquin) prevention of malaria.
- Explain the use of acyclovir in the treatment of *Herpes simplex* infection.
- Explain the mechanisms by which bacteria increase their drug resistance susceptibility.
- Explain, using principles of viral oncogenesis, how *Herpes simplex* can lead to cervical carcinoma.

2. Apply the principles of symbiosis (commensalisms, mutualism, and parasitism) to the maintenance of health and disease.

Examples:

- Explain the pathogenetic roles of *Streptococcus pneumoniae* in pneumonia following influenza infection.
- Explain the protective effect of normal gut flora and its perturbation after antibiotic treatment.

3. Apply the principles of epidemiology to maintaining and restoring the health of communities and individuals.

Examples:

- Explain the role of genetic drift and shift in the generation of epidemic and pandemic influenza.
- Explain the influence of timing of infection and host response to the clinical expression of hepatitis B infection.
- Relate changes in lifestyle to the emergence of pathogens, such as *Legionella pneumophila* or SARS coronavirus.

Competency M7

Apply the principles of pharmacology to evaluate options for safe, rational, and optimally beneficial drug therapy.

Learning Objectives:

1. Apply knowledge of pathologic processes, pharmacokinetics, and pharmacodynamics to guide safe and effective treatments.

Examples:

- Utilize multiple drugs with different mechanisms of action for cancer chemotherapy.
- Explain the differences in response to enantiomeric drugs.
- Explain how proper therapeutic strategies help minimize or prevent drug resistance.
- Modify drug dosage according to renal function.
- Consider food–drug and drug–drug interactions in drug dosing.

2. Select optimal drug therapy based on an understanding of pertinent research, relevant medical literature, regulatory processes, and pharmacoeconomics.

Examples:

- Explain why a generic drug might or might not be chosen over a proprietary drug.
- Explain the process by which drugs become approved and withdrawn in the United States.
- Describe the limitations of the claims for therapeutic efficacy and safety as they might be reported by a pharmaceutical manufacturer.

3. Apply knowledge of individual variability in the use and responsiveness to pharmacological agents to selecting and monitoring therapeutic regimens and identifying adverse responses.

Examples:

- Use pharmacogenetic tests in situations of demonstrated clinical utility.
- Individualize drug therapy to maximize benefit and minimize adverse effects.
- Design a therapeutic regimen that incorporates monitoring of drug levels and/or efficacy and appropriate dosage adjustment.

Competency M8

Apply quantitative knowledge and reasoning—including integration of data, modeling, computation, and analysis—and informatics tools to diagnostic and therapeutic clinical decision making.

Learning Objectives:

1. Apply basic mathematical tools and concepts, including functions, graphs and modeling, measurement and scale, and quantitative reasoning, to an understanding of the specialized functions of membranes, cells, tissues, organs, and the human organism, in both health and disease.

Examples:

- Interpret graphical representations of drug levels as a function of dosage and pharmacokinetics.
- Given urine and serum creatinine levels, urine flow rate, height, and weight, calculate the estimated GFR (glomerular filtration rate).
- Draw a graph of serum glucose levels after a meal, and explain how feedback mechanisms lead to damped oscillations in glucose levels.

2. Apply the principles and approaches of statistics, biostatistics, and epidemiology to the evaluation and interpretation of disease risk, etiology, and prognosis, and to the prevention, diagnosis, and management of disease.

Examples:

- Contrast relative risk and attributable risk as guides to clinical and public health decision making in cancer prevention.
- Compare information derived from confidence intervals and probability values in determining the significance of an association between estrogen treatment and cardiovascular disease.
- Explain methods used to adjust for confounding factors in determining the prognosis in HIV infection.
- Relate the characteristics of a diagnostic medical test to its ability to discriminate between health and disease given the prevalence of the disease.

3. Apply the basic principles of information systems, their design and architecture, implementation, use, and limitations, to information retrieval, clinical problem solving, and public health and policy.

Examples:

- Perform a search of PubMed or other bibliographic databases (such as PSYCHINFO, INSPEC, or Sociological Abstracts), using at least two Boolean connectors, on a clinical topic.
- Explain the difference between an electronic medical record system and a computerized provider order entry system and their roles in patient safety.
- Describe the uses and limitations of a clinical data warehouse as a research tool.
- Explain the concept and importance of information system interoperability.

4. Explain the importance, use, and limitations of biomedical and health informatics, including data quality, analysis, and visualization, and its application to diagnosis, therapeutics, and characterization of populations and subpopulations.

Examples:

- Explain the difference between biomedical informatics and health care information technology.
- Provide examples of how informatics can contribute to health care quality.
- Explain the ways clinical information systems can fail.

5. Apply elements of the scientific process, such as inference, critical analysis of research design, and appreciation of the difference between association and causation, to interpret the findings, applications, and limitations of observational and experimental research in clinical decision making.

Examples:

- Contrast the value of evidence from observational versus experimental studies in determining the efficacy of therapeutic interventions.
- Analyze the causal connection between dietary factors and coronary artery disease incidence.
- Using the same empirical data, provide arguments for and against routine PSA screening for prostate cancer.

- Recognize that human decision making generally weights only a limited set of factors at one time, and be able to use tools and methods that consider multiple factors and uncertainties.
- Recognize when patients are excluding important information in their decision-making processes.

Entering Medical Student Expectations

Premedical students, no matter what their primary fields of study, should learn the major concepts and skills of science and mathematics, leaving to medical schools the task of building on this scientific foundation the further scientific competencies that provide them the ability to practice science-based medicine.

Overarching Competency at the Time of Entry into Medical School:

Demonstrate both knowledge of and ability to use basic principles of mathematics and statistics, physics, chemistry, biochemistry, and biology needed for the application of the sciences to human health and disease; demonstrate observational and analytical skills and the ability to apply those skills and principles to biological situations.

Competency E1

Apply quantitative reasoning and appropriate mathematics to describe or explain phenomena in the natural world.

Learning Objectives:

1. Demonstrate quantitative numeracy and facility with the language of mathematics.

Examples:

- Express and analyze natural phenomena in quantitative terms that include an understanding of the natural prevalence of logarithmic/exponential relationships (e.g., rates of change, pH).
- Explain dimensional differences using numerical relationships, such as ratios and proportions.
- Use dimensional analysis and unit conversions to compare results expressed in different systems of units.
- Utilize the Internet to find relevant information, synthesize it, and make inferences from the data gathered.

2. Interpret data sets and communicate those interpretations using visual and other appropriate tools.

Examples:

- Create and interpret appropriate graphical representations of data, such as a frequency histogram, from discrete data.
- Identify functional relationships from visually represented data, such as a direct or inverse relationship between two variables.
- Use spatial reasoning to interpret multidimensional numerical and visual data (e.g., protein structure or geographic information).

3. Make statistical inferences from data sets.

Examples:

- Calculate and explain central tendencies and measures of dispersion.
- Evaluate hypotheses using appropriate statistical tests.
- Evaluate risks and benefits using probabilistic reasoning.
- Describe and infer relationships between variables using visual or analytical tools (e.g., scatter plots, linear regression, network diagrams, maps).
- Differentiate anomalous data points from normal statistical scatter.

4. Extract relevant information from large data sets.

Examples:

- Execute simple queries to search databases (e.g., queries in literature databases).
- Compare data sets using informatics tools (e.g., BLAST analysis of nucleotide or amino acid sequence).
- Analyze a public-use data set (e.g., census data, NHANES, BRFSS).

5. Make inferences about natural phenomena using mathematical models.

Examples:

- Describe the basic characteristics of models (e.g., multiplicative vs. additive).
- Predict short- and long-term growth of populations (e.g., bacteria in culture).
- Distinguish the role of indeterminacy in natural phenomena and the impact of stochastic factors (e.g., radioactive decay) from the role of deterministic processes.

6. Apply algorithmic approaches and principles of logic (including the distinction between cause/effect and association) to problem solving.

Examples:

- Define a scientific hypothesis and design an experimental approach to test its validity.
- Utilize tools and methods for making decisions that take into account multiple factors and their uncertainties (i.e., a decision tree).
- Critically evaluate whether conclusions from a scientific study are warranted.
- Distinguish correlation from causality.

7. Quantify and interpret changes in dynamical systems.

Examples:

- Describe population growth using the language of exponents and of differential calculus.
- Explain homeostasis in terms of positive or negative feedback.
- Calculate return on investment under varying interest rates by utilizing appropriate mathematical tools.

Competency E2

Demonstrate understanding of the process of scientific inquiry, and explain how scientific knowledge is discovered and validated.

Learning Objectives:

1. Develop observational and interpretive skills through hands-on laboratory or field experiences.

Examples

- Collect and interpret primary data for identification of mixtures of compounds.
- Use reduced or partial data to construct three-dimensional representations (e.g., developing organic molecular models from written formulas or modeling a biological structure from analysis of serial sections).
- Demonstrate ability to analyze and infer conclusions based on measurements made during laboratory assays or field observations.

2. Demonstrate ability to measure with precision, accuracy, and safety.

Examples:

- Consider the accuracy, precision, and reproducibility of primary data from laboratory results to properly analyze and draw conclusions, including the differences between random and systematic sources of error.
- Employ stoichiometric analysis to predict yield and use quantitative measurements to interpret experimental results.
- Be able to use a standard Material Safety Data Sheets (MSDS) to decide on appropriate personal protection and disposal techniques for use of a given chemical.

3. Be able to operate basic laboratory instrumentation for scientific measurement.

Examples:

- Employ appropriate instrumentation to measure electrical voltages and currents in simple circuits.
- Use appropriate detectors and instrumentation to monitor radioactive decay.
- Calibrate a balance.
- Be familiar with instruments and approaches for major chemical and biochemical separation and purification techniques.
- Identify major chemical or biochemical uses of analytical spectroscopic techniques, such as UV, visible and infrared absorption, fluorescence, mass spectrometry, X-ray, and NMR.

4. Be able to articulate (in guided inquiry or in project-based research) scientific questions and hypotheses, design experiments, acquire data, perform data analysis, and present results.

Examples:

- Be able to develop a project plan and report: generate a hypothesis, design a protocol with appropriate controls, consider control of relevant variables, collect and analyze quantitative data, draw conclusions, and present the results (e.g., as a scientific seminar, paper, or poster).
- Be able to work within a team to plan and/or achieve a complex goal (e.g., a presentation or an experiment that draws on more than one scientific discipline).

- Be able to read and analyze results presented in a paper from the scientific literature, to develop a hypothesis based on the results, and to describe experiments that test such a hypothesis.
 - Develop an exemplary design to achieve a goal, such as an electronic circuit, a molecular synthesis, or an enzyme assay.
 - Be able to explain what constitutes plagiarism in contexts of writing and presentation and how to avoid and prevent the falsification and fabrication of data.
5. Demonstrate the ability to search effectively, to evaluate critically, and to communicate and analyze the scientific literature.

Examples:

- Use appropriate databases to find relevant literature on a topic, and be able to summarize and present the current state of knowledge.
- Evaluate papers in the literature with attention to weaknesses, such as in experimental design (e.g., confounding variables), logic, or conclusions.

Competency E3

Demonstrate knowledge of basic physical principles and their applications to the understanding of living systems.

Learning Objectives:

1. Demonstrate understanding of mechanics as applied to human and diagnostic systems.

Examples:

- Explain the interrelationships among work, energy, force, and acceleration.
- Apply knowledge of centripetal acceleration to “g-force” devices used to train jet pilots and astronauts.
- Explain the mechanical basis for molecular and cellular separation technologies (i.e., centrifugation and chromatography).
- Apply knowledge of mechanics to movement in biological systems at various scales, from the molecular to the organismal.

2. Demonstrate knowledge of the principles of electricity and magnetism (e.g., charge, current flow, resistance, capacitance, electrical potential, and magnetic fields).

Examples:

- Explain how the time to charge or discharge a capacitor depends on the capacitance and the resistance in the charging or discharging circuit.
- Apply concepts of resistance and capacitance to the electrical properties of myelinated and unmyelinated axons and how those properties affect the travel speed of action potentials in those types of neurons.
- Apply understanding of electrical principles to the hazards of electrical currents and voltages.
- Describe how electrical currents establish magnetic fields and how time-varying magnetic fields induce electrical currents in materials, such as metals or biological tissue.

Comprehensive Review of the USMLE

Potential changes in the United States Medical Licensing Examination (USMLE) also offer an opportunity to advance the goals outlined in this report. A strategic review of the USMLE by the Composite Committee, which establishes policy for the national licensure examination, found that the “USMLE should seek to better merge the assessment of the science important to medicine with the assessment of clinical knowledge and skills important to practice.” The Committee has identified guiding principles for the USMLE going forward. These principles state that the primary purpose of the USMLE is to inform the medical licensing process by assessing the competencies of physicians wishing to practice medicine within the United States. The panel has stated that “competencies considered central to safe and effective patient care are dynamic” and that “the USMLE should be responsive as national consensus about core competencies evolves.” The Composite Committee has recommended that the “USMLE emphasize the importance of the scientific foundations of medicine in all components of the assessment process.” The competencies outlined in this report are expected to contribute to the national consensus process envisioned by the Composite Committee. Operational, structural, and content changes to the exam are continuing to be explored and the implementation of any changes will be accomplished over several years.

3. Demonstrate knowledge of wave generation and propagation to the production and transmission of radiation.

Examples:

- Apply geometric optics to understand image formation in the eye.
- Apply wave optics to understand the limits of image resolution in the eye.
- Apply knowledge of sound waves to describe the use and limitations of ultrasound imaging.

4. Demonstrate knowledge of the principles of thermodynamics and fluid motion.

Examples:

- Explain mechanisms of heat transfer.
- Apply knowledge of the laws of thermodynamics to processes at various scales.
- Explain the thermodynamics of simple diffusion through biological membranes.
- Explain how viscosity affects blood flow.

5. Demonstrate knowledge of principles of quantum mechanics, such as atomic and molecular energy levels, spin, and ionizing radiation.

Examples:

- Use knowledge of atomic structure to explain the origin of ionizing radiation and its interaction with matter.
- Apply physical principles to explain the generation, detection, and analysis of magnetic resonance signals.
- Apply knowledge of molecular energy levels to explain how structural information is obtained from vibrational spectroscopy.
- Apply the principles of electromagnetic radiation and its interactions with matter.

6. Demonstrate knowledge of principles of systems behavior, including input–output relationships and positive and negative feedback.

Examples:

- Use input–output relationships to understand the efficiency of converting food energy into muscular motion.

- Apply negative feedback principles to explain how temperature is regulated in buildings and in the human body.
- Apply positive feedback principles to explain action potentials.

Competency E4

Demonstrate knowledge of basic principles of chemistry and some of their applications to the understanding of living systems.

Learning Objectives:

1. Demonstrate knowledge of atomic structure.

Examples:

- Use atomic structure in terms of atomic orbitals and periodicity of atomic properties to explain chemical reactivity.
- Define the structural nature and characteristics of isotopes and explain how their use as biological tracers may—or may not—be appropriate.

2. Demonstrate knowledge of molecular structure.

Examples:

- Apply theories of ionic bonding and intramolecular covalent bonding built on the principles of electrostatics, hybridization, molecular orbital theory, to explain molecular characteristics such as electronegativity, and bond strengths and angles.
- Predict molecular geometry, including occurrence of isomerism.
- Use rules of nomenclature for covalent and ionic compounds (e.g., be able to identify molecular structures and formulas, know names of functional groups).
- Explain how molecular structure is determined by X-ray diffraction and spectroscopic methods.

3. Demonstrate knowledge of molecular interactions.

Examples:

- Distinguish between ionic interactions, van der Waals interactions, hydrogen bonding, and hydrophobic interactions.
- Apply this knowledge to understanding of the structures of macromolecules, liquids (especially water), and solids.

- Apply this knowledge to understanding of biological macromolecules and biological assemblies, such as membranes.

4. Demonstrate knowledge of thermodynamic criteria for spontaneity of physical processes and chemical reactions and the relationship of thermodynamics to chemical equilibrium.

Examples:

- Apply the laws of thermodynamics to carry out thermochemical calculations.
- Apply the concepts of acid-base equilibria.
- Apply the concepts of equilibrium electrochemistry and of concentration cells.
- Apply understanding of these concepts to biochemical processes, such as metabolism, photosynthesis, and electrochemical processes in cell membranes.

5. Demonstrate knowledge of principles of chemical reactivity to explain chemical kinetics and derive possible reaction mechanisms.

Examples:

- Explain how measurements of reaction rates lead to the determination of rate laws.
- Explain the temperature dependence of reaction rates.
- Apply understanding of these concepts to predict biochemical processes, such as enzyme catalysis.

6. Demonstrate knowledge of the chemistry of carbon-containing compounds relevant to their behavior in an aqueous environment.

Examples:

- Recognize major types of functional groups and chemical reactions.
- Explain how molecular structure and geometry, including chirality, relate to chemical reactivity.
- Explain the chemical principles that allow structural inference about bio-organic molecules based on common spectroscopic analyses, such as NMR, UV/visible/IR absorption, or X-ray diffraction.
- Apply knowledge of the chemistry of covalent carbon compounds to explain biochemical reactions.

Competency E5

Demonstrate knowledge of how biomolecules contribute to the structure and function of cells.

1. Demonstrate knowledge of the structure, biosynthesis, and degradation of biological macromolecules.

Examples:

- Identify the major macromolecules (proteins, nucleic acids, carbohydrates, and lipids) and explain the way in which their structure affects their properties.
- Explain how hydrophobicity and hydrophilicity drive molecular association and contribute to both specificity and affinity.
- Explain how protein, nucleic acid, carbohydrate, and lipid degradation and recycling are essential to normal cell function.

2. Demonstrate knowledge of the principles of chemical thermodynamics and kinetics that drive biological processes in the context of space (i.e., compartmentation) and time: enzyme-catalyzed reactions and metabolic pathways, regulation, integration, and the chemical logic of sequential reaction steps.

Examples:

- Identify the six major types of biochemical reactions (oxidation-reduction, group transfer, hydrolysis, isomerization, ligation, lysis).
- Distinguish different types of enzyme control, such as feedback, competitive and noncompetitive inhibition, and allosteric effects.
- Explain how membrane gradients and electron transport act to generate and store energy.
- Explain how glucose transport across epithelia depends on the sodium concentration gradient.
- Describe the role of the Na-K-ATPase in the maintenance of the resting membrane potential of cells.
- Explain how energy stored in ATP is transduced by motor proteins to produce movement.
- Explain the chemical logic of the glycolytic pathway.
- Explain how energy is stored in fatty acids and complex lipids.

3. Demonstrate knowledge of the biochemical processes that carry out transfer of biological information from DNA, and how these processes are regulated.

Examples:

- Give examples of how mutations in specific DNA sites affect the protein product.
 - Explain how control of gene expression through differential transcription factors, chromatin remodeling, and alternative splicing enables cell differentiation.
 - Explain how RNAi influences translation and protein synthesis.
4. Demonstrate knowledge of the principles of genetics and epigenetics to explain heritable traits in a variety of organisms.

Examples:

- Explain the modes of single gene inheritance.
- Explain normal sources of genetic variability, such as mutation, independent assortment, and crossing over.
- Explain how X-inactivation leads to mosaicism in female mammals.

Competency E6

Apply understanding of principles of how molecular and cell assemblies, organs, and organisms develop structure and carry out function.

Learning Objectives:

1. Employ knowledge of the general components of prokaryotic and eukaryotic cells, such as molecular, microscopic, macroscopic, and three-dimensional structure, to explain how different components contribute to cellular and organismal function.

Examples:

- Describe how the internal organization of a cell changes as it begins cell division.
- Describe how proteins are targeted to different compartments in eukaryotic cells.
- Describe the role of the cytoskeleton in amoeboid movement of cells.

2. Demonstrate knowledge of how cell–cell junctions and the extracellular matrix interact to form tissues with specialized function.

Examples:

- Describe the structure and explain how gap junctions and other forms of cell–cell interfaces facilitate communication between cells.
- Explain how myelinated axons accelerate the conduction of action potentials as compared to unmyelinated axons.
- Explain how variations in cell–cell junctions influence the permeability of epithelial tissues to solutes and water.

3. Demonstrate knowledge of the mechanisms governing cell division and development of embryos.

Examples:

- Explain why and how only maternal mitochondria are passed to the embryo.
- Explain how abnormal processes in meiosis gives rise to genetic anomalies, such as trisomy 21, Turner’s (X) syndrome, and Klinefelter’s (XXY) syndrome.
- Describe the chemical signaling that controls normal cell division and apoptosis.
- Explain the hormonal basis for the menstrual cycle in humans.

4. Demonstrate knowledge of the principles of biomechanics and explain structural and functional properties of tissues and organisms.

Examples:

- Apply understanding of force and torque to explain why small differences in muscle insertion make a significant difference in the speed and force created by limb movement.
- Explain the role of motor proteins in contraction and cellular movement.
- Explain the physics of how blood movement and pressure are affected by vessel diameter.

Competency E7

Explain how organisms sense and control their internal environment and how they respond to external change.

Learning Objectives:

1. Explain maintenance of homeostasis in living organisms by using principles of mass transport, heat transfer, energy balance, and feedback and control systems.

Examples:

- Explain the role of CO₂ in the maintenance of pH homeostasis.
- Explain the mechanisms by which cells maintain cell volume in the face of changing extracellular osmolarity.
- Explain an example of how pumps move substrates and fluids within the body, or between the internal and external environments.
- Explain how the competing needs to exchange gases and retain water are met in terrestrial organisms.

2. Explain physical and chemical mechanisms used for transduction and information processing in the sensing and integration of internal and environmental signals.

Examples:

- Explain how altering ion channel permeability contributes to electrical signaling within and between cells.
- Describe how chemoreceptors sense and transduce various chemical signals from the internal and external environments.
- Explain how organisms sense and adapt to a change in environmental temperature.
- Explain the role of both the nervous system and endocrine system in maintaining blood glucose levels.

3. Explain how living organisms use internal and external defense and avoidance mechanisms to protect themselves from threats, spanning the spectrum from behavioral to structural and immunologic responses.

Examples:

- Describe how the immune system differentiates between self and non-self.
- Explain why the digestive tract has the largest amount of immune tissue.

- Explain how adrenal hormones affect behavior in fight-or-flight situations.

Competency E8

Demonstrate an understanding of how the organizing principle of evolution by natural selection explains the diversity of life on earth.

1. Explain how genomic variability and mutation contribute to the success of populations.

Examples:

- Explain how inappropriate use of antibiotics has contributed to the evolution of antibiotic-resistant strains of bacteria.
- Explain the persistence of the sickle cell allele in populations of African descent.

2. Explain how evolutionary mechanisms contribute to change in gene frequencies in populations and to reproductive isolation.

Examples:

- Explain how competition for resources can contribute to fixation of a mutant allele in a population over time.
- Explain how pathogenic or symbiotic interactions shape community structure (for example, changes in the virulence of an emerging pathogen, or influence of nutrition or antibiotics on the composition of the gut flora).

Beginning a dialogue at your institution: Questions to consider

- What are the opportunities and challenges in implementing a competency-based curriculum approach?
- What role can faculty play in advancing curricular change?
- How long will it take to implement changes in the curriculum to reflect desired competencies?
- How can undergraduate institutions and medical schools work together to achieve continuity in the scientific preparation of physicians?
- How can AAMC or HHMI assist those institutions that wish to modify their curricula?
- Should premedical course requirements be modified to reflect achieved competencies rather than courses taken?
- How would premedical course requirement changes be implemented?
- Are there resources that can be developed to help institutions with limited resources work toward a competency based curricular approach?
- How will student achievement of the competencies be assessed at the undergraduate level? At the medical school level?
- How will these competencies evolve as knowledge expands?
- How can institutions provide input to the MCAT review committee (MR5) on the content of current and future MCAT exams?

The Challenge of Implementation

In this report, the SFFP committee provides guidelines to facilitate and promote curricular change. These recommendations are not intended to be a mandate. Further, the committee does not propose an increase in the number of requirements, but it does propose substitution of more relevant requirements for some that are less relevant. In most institutions, existing courses that meet the current recommendations for premedical study, plus added learning experiences—for example, in statistics—can be used to prepare students to meet the recommended competencies. However, the committee strongly encourages the design of new curricula that would create synergies and exciting new learning experiences, and foster partnerships across disciplines.

How can individuals and institutions begin to use the competencies outlined in this report, as they consider curricula and the educational process for preparing future physicians? Carracio and colleagues reviewed implementation of competency-based education,¹³ and reported that a stepwise approach to curricular design was adopted most often. The four steps are: 1) identification of competencies; 2) determining the components of the competency and the expected performance levels; 3) assessment of the competency; and 4) overall assessment of the process.

Step one, identification of competencies, was the work of the committee and the substance of this report. The committee also discussed envisioning numerous examples of measurable tasks that, in the aggregate, could determine whether a student has achieved the given competency. It is the committee's view that colleges and medical schools should set the expected performance level for each task. These expectations must be stated clearly for current and future students, and for the faculty developing curricula.

Carracio et al. concluded that assessment of the competency—the third step—is preferably accomplished by criterion-reference measures that compare performance against a set standard or threshold. Why a threshold rather than a normative-based assessment? A normative-based assessment compares the student's performance with that of a peer group, but this type of assessment does not provide a clear understanding of what the student can or cannot do. Carracio and colleagues state that the key to the overall assessment of the process is to create a direct link between the desired competencies and the curricular objectives. During the fourth step, the competencies, attainment system, and assessment system are validated.

A fundamental component of any curricular change is to ensure that the faculty ultimately responsible for the education of students and physicians assume responsibility for determining the knowledge, attitudes, and skills required to achieve the competencies. This requires creating faculty development programs and assuring that the role of the teacher is valued and acknowledged.¹⁴

There have been several reports written during the past decade focused on curriculum change strategies in U.S. undergraduate colleges and medical schools^{6, 15, 16} that may be used as examples. Each undergraduate school must

determine how best to design their curricula so that premedical students may achieve the desired competencies for medical school entry. Innovative curricula may help not only premedical candidates, but also students across the whole span of the sciences. Medical schools must decide the minimal level of knowledge and skills that their graduates must possess in these competency domains. Most medical schools pursue a four-year curriculum with many competing demands for curricular time and attention. Ultimately, undergraduate colleges and medical schools must approach curriculum design in the way that best suits the goals and the culture of their institutions. Just as there is no single approach to curriculum change, every institution must consider the environment, culture, and desired outcomes of its educational program when considering what changes to make.

The SFFP committee drew its membership from a variety of medical and basic science disciplines. A rewarding outcome of committee work was the dialogue across disciplines. Comparable discussions at institutions across the spectrum of undergraduate and medical schools are a key to curricular change. It is the committee's belief that at both levels—medical school and undergraduate schools—interdisciplinary approaches are an important component of the needed new directions in science education. Lively dialogues about and innovations in curricula will contribute to the education of visionary leaders in the next generation of physicians.

Updating or Changing Competencies

The movement to competency-based education began in the 1970s and has gained considerable momentum in the past decade. Educators recognized the value of using the competency approach to guide educational program design—to develop specific learning objectives for each competency. The AAMC's Medical School Objectives Project (MSOP) was established to help medical schools determine the outcomes of the medical student education program, and the Accreditation Council on Graduate Medical Education (ACGME) subsequently established six core competencies for graduate medical education programs. The MSOP project and other competencies explicitly recognize the need to change and adapt competencies to meet changing educational, science, and health care developments.

Given the need for curricular renewal, the committee recommends that the competencies in this report be reviewed on a regular basis and revised to reflect changes that will occur in the sciences, in our expectations of physicians, and in the health care system. It will be incumbent on each institution to consider whether the competencies and their corresponding objectives are adequate and accurately reflect the outcomes the school or university desires. School leadership can help facilitate conversations and create incentives that promote cooperation among departments.

Summary As the scientific knowledge base important to the learning and practice of medicine continues to change, the premedical and medical curricula must evolve to equip future physicians with a strong scientific foundation upon which to initiate modern medical practice. The premedical and medical curricula must foster scholastic rigor, analytical thinking, quantitative assessment, and analysis of complex systems in human biology. Scientific competencies should embrace recent advances in the foundational sciences and emphasize the increasingly close relationship of the physical and mathematical sciences with the practice of medicine.

In the AAMC's *Report of the Ad Hoc Committee of Deans*¹⁵ the authors state, "The [ideal medical] system can meet its unique responsibility to educate and train highly competent medical practitioners only by ensuring that they acquire and possess throughout their careers the knowledge, skills, attitudes, and values needed for medical practice as members of an interdisciplinary health care team, and the ability to perform the complex, integrative tasks required to provide high-quality care to the patients who seek their help."

The principles, competencies, and objectives laid out in this report are presented as a blueprint, which can be used by educators to design premedical and medical school educational programs. A competency-based approach should give both learners and educators more flexibility in the premedical curriculum to allow undergraduate institutions to develop more interdisciplinary and integrative courses that maintain scientific rigor, while providing a broad and strong liberal arts education. Entering medical students should be more evenly prepared for the study of medicine, allowing medical schools to spend less time teaching or reviewing the basic competencies and more time learning the growing scientific knowledge base needed to practice modern medicine.

The report represents the beginning of a broad dialogue within the undergraduate and medical education communities to reinvigorate the scientific preparation of physicians. Although the committee recognizes that there are challenges in implementing a competency-based system, this report is intended to represent a first step in a continuing conversation about the appropriate skills, knowledge, values, and attitudes that future physicians should possess.

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