Chemistry and the Premedical Curriculum: The Impact of MCAT$^{2015}$

Chemical Sciences Roundtable
May 22, 2013

Joel Shulman
University of Cincinnati

- Advocates a focus on competencies rather than on specific courses taken or disciplines studied
- Targets both premedical and medical education
A Goal of the AAMC: Transforming Admissions to Medical School

• Transforming admissions to keep pace with changes in science and medical education

• Preparing a physician workforce to improve the health of all
What is “competency”? A combination of skills, abilities, and knowledge needed to perform a specific task.

What is “scientific competency” in medical practice? Knowledge, skills and habits of mind needed to understand scientific concepts and discoveries, to integrate them into medical practice, and to communicate them effectively to patients.
Implications for Medical School Admission

• SFFP (and thus, AAMC) recommends that medical schools reassess their current prerequisite course requirements with a focus on creating the least-restrictive pathway for applicants.
  
  • Decouple specific prerequisites from desired outcomes of premedical education
  
  • Competency-Based Admissions: **ability to demonstrate** a core set of **entry-level competencies** needed to succeed in medical school, in residency, and in practice
  
  • Assess newly defined scientific competencies “credibly and reliably” by the MCAT®
Blue-ribbon Panel Reports

- Behavioral and Social Science Foundations for Future Physicians (2011)
MCAT²⁰¹⁵ – 4 Sections, 4 Scores

- Biological & Biochemical Foundations of Living Systems
- Chemical & Physical Foundations of Biological Systems
- Psychological, Social, & Biological Foundations of Behavior
- Critical Analysis & Reasoning Skills
Critical Analysis & Reasoning Skills

- Asks examinees to critically analyze, evaluate, and apply information presented in passages from humanities and social sciences, including:
  - Ethics
  - Philosophy
  - Population health
  - Cross-cultural studies
- Specific disciplinary knowledge not needed
Competencies for Entering Medical Students

Competency E1
Application of quantitative reasoning and appropriate mathematics to describe or explain phenomena in the natural world.

Competency E2
Demonstrate understanding of the process of scientific inquiry, and explain how scientific knowledge is discovered and validated.

Competency E3
Demonstrate knowledge of basic physical principles and their applications to the understanding of living systems.

Competency E4
Demonstrate knowledge of basic principles of chemistry and some of their applications to the understanding of living systems.

Competency E5
Demonstrate knowledge of how biomolecules contribute to the structure and function of cells.

Competency E6
Apply understanding of principles of how molecular and cell assemblies, organs and organisms develop structure and carry out function.

Competency E7
Explain how organisms sense and control their internal environment and how they respond to external change.

Competency E8
Demonstrate an understanding of how the organizing principle of evolution by natural selection explains the diversity of life on earth.
Competency E4: Examples of Learning Objectives

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

  – *Demonstrate knowledge of atomic structure.*
  – *Demonstrate knowledge of molecular structure.*
  – *Demonstrate knowledge of (inter)molecular interactions.*
  – *Demonstrate knowledge of thermodynamic criteria for spontaneity of physical processes and chemical reactions.*
  – *Demonstrate knowledge of the chemistry of carbon-containing compounds relevant to their behavior in an aqueous environment.*
**Combining Skills and Concepts**

<table>
<thead>
<tr>
<th>Foundational Concept 1</th>
<th>Foundational Concept 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Content Category</strong></td>
<td><strong>Content Category</strong></td>
</tr>
<tr>
<td>1A</td>
<td>2A</td>
</tr>
<tr>
<td>1B</td>
<td>2B</td>
</tr>
<tr>
<td>1C</td>
<td>2C</td>
</tr>
</tbody>
</table>

- Each cell represents the point at which foundational concepts, content categories, and scientific inquiry and reasoning skills cross.
- Test questions are written at the intersections of the content and skills.
Foundational Concept 5

- The principles that govern chemical interactions and reactions form the basis for a broader understanding of the molecular dynamics of living systems.
The Biological and Biochemical Foundations of Living Systems and the Chemical and Physical Foundations of Biological Systems sections are designed to:

- test introductory-level biology, organic and inorganic chemistry, and physics concepts;
- test biochemistry concepts at the level taught in many colleges and universities in first-semester biochemistry courses;
- test cellular/molecular biology topics at the level taught in many colleges and universities in introductory biology sequences;
- target basic research methods and statistics concepts described by many baccalaureate faculty as important to success in introductory science courses; and
- require students to demonstrate their scientific inquiry and reasoning, research methods, and statistics skills as applied to the natural sciences.
Approximate Distribution of Questions

- General chemistry: 30%
- Organic chemistry: 25%
- First-semester biochemistry: 15%
- Introductory physics: 25%
- Introductory biology: 5%
Competencies may be best developed within an interdisciplinary context

• Apply concepts of chemistry to biological examples in biology courses?

• Explore basic chemistry principles within biological contexts in chemistry courses?

Or both?
Should the Chemistry Curriculum Change in Response to MCAT\textsuperscript{2015}?  

• Currently, most pre-medical students complete five semesters of chemistry:  
  – one year of general chemistry  
  – one year of organic chemistry  
  – one semester of biochemistry  

• It is not obvious that any change is \textit{required}.  

• However, SFFP presents both \textit{opportunities} and \textit{challenges} for the chemistry community.
Opportunities Catalyzed by SFFP

• Recognize that most freshman and sophomore chemistry students—not only premeds—have a strong biological interest.
  – Introduce more biological examples into both general and organic chemistry.
  – Take advantage of the flexibility in the 2008 ACS Guidelines for Undergraduate Professional Education in Chemistry to reorganize chemistry programs.
    • Guidelines require at a minimum the equivalent of a one-semester course in each of the five major areas of chemistry.
    • Guidelines do not require two semesters of any given area of chemistry, including organic.
Examples of Curricular Modifications to Meet the Interests of Premeds and Others

• Traditional curriculum: One year each of general chemistry and organic chemistry
• Second semester of organic offered as a choice between “Bioorganic” or “Mechanism & Synthesis”
• 1-2-1 approach
• Organic first
• Fully integrated foundation courses

All of these approaches assume a separate one- or two-semester biochemistry course.
Traditional Approach: One Year Each of General and Organic Chemistry

• Integrate biological examples whenever possible.
  – Enzyme catalysis, including the role of proximity within the active sites and the influence of nonbonding interactions
  – Peptide bonds and protein conformations when discussing carboxylic acid derivatives
  – Monosaccharide structure and mutorotation when discussing hemiacetal and acetal formation
  – Converting –OH to phosphate or sulfate ester leaving groups
  – Biologically relevant reactions in addition to standard synthetic reactions
    • NADH as a reducing agent
    • Claisen condensation of acetyl CoA to form acetoacetyl CoA
Second-Semester Organic: Bioorganic or Mechanism & Synthesis

• First semester of organic: Introduce most of the major concepts, including functional groups and some spectroscopy

• Second semester, offer a choice of two courses
  – Bioorganic, for premeds and other biology-oriented students
  – Mechanism and Synthesis, with emphasis on retrosynthesis and physical organic, for majors, chemical engineers, etc.

• Obviously depends on available teaching resources to present two different second-semester courses
1-2-1 Approach

- A two-year curriculum consisting of a semester of general chemistry, two semesters of organic, then one of biochemistry
  - HHMI grant to Purdue to develop a 1-2-1 approach based closely on the SFFP competencies
  - General chemistry can have a strong acid-base approach with connections to biochemistry
  - Organic emphasizes reactions and mechanisms with biochemical analogies, de-emphasizes retrosynthesis and organometallics
  - Assumes freshman are adequately prepared so that one semester of general chemistry is sufficient for success in organic
Organic First

• Freshmen start with “biologically flavored” organic
  – Not a traditional organic course
  – Rather, introduces some general-chemistry concepts intercalated with relevant biologically related material

• This can be followed by
  – Two semesters of mainstream chemistry (e.g., inorganic and analytical); or
  – One mainstream chemistry course and a biochemistry course
An Example of Fully Integrated Foundation Courses*

• Replace the standard first two years of chemistry
  – Structure and Properties (one semester)
  – Reactivity I, II, and III (three semesters)

• Integrate structure and reactivity in the context of organic, inorganic, and biochemistry
  – Link topics so that students can see their relevance to society
  – Coordinate with the SFFP and MCAT^2015 competencies

• Demonstrate to ACS Committee on Professional Training that these courses meet the Guidelines for approval

* College of St. Benedict-St. John’s University
Some Challenges Presented by SFFP

• Ability of smaller schools to accommodate the chemistry requirement of all majors

• Curricular change takes
  – Buy-in from full faculty and coordination among departments
  – Availability of appropriate texts

• Articulation between two- and four-year colleges with modified curriculum

• Availability of resources to teach modified courses

• Possible reduction of TA needs/support
Some Unanswered Questions Raised in Response to SFFP

• Will medical schools have the ability and desire to adjust admission criteria to reflect competencies?
• Will undergraduate programs be motivated to map courses to premedical competencies?
• Will MCAT\textsuperscript{2015} be successful in assessing competencies “credibly and reliably”?
• Will MCAT\textsuperscript{2015} minimize emphasis on “non-biologically relevant” chemistry?
  – Two examples of content that may be tested*:
    • Grignard reagents
    • Preparation of mesylates and tosylates

* Preview Guide for the MCAT\textsuperscript{2015} Exam
Another Interesting Challenge

Response to the new MCAT

ASBMB premedical curriculum recommendations

BY CHARLES BRENNER AND DAMANPRAKASH

EDITORS NOTE: At the December Council meeting of the American Society for Biochemistry and Molecular Biology, President Susan Pfister tasked Charles Brenner with developing premedical curriculum recommendations consistent with the Medical College Admission Test, a revision of which will be rolled out in 2016. Brenner is the Roy I. Farmer chair and head of biochemistry at the University of Iowa, a department responsible for teaching undergraduate, graduate, medical, and health professional students. After investigating premedical education at 10 universities and several others, Brenner turned to Dagmar Ringo, the Harold and Eunice Harris professor of aging and neurodegenerative disease in the departments of chemistry and biochemistry at Stanford University, to develop recommendations. Ringo also is an organic chemistry and biochemistry textbook author and a former director of the organic chemistry laboratory course at Massachusetts Institute of Technology. ASBMB encourages your feedback, critique, and/or support for the recommendations presented here. Please visit it at www.asbmb.org/asbmbday.

Many college students plan their curricula based on medical school admissions requirements. Enrollment in undergraduate biology, chemistry, physics, and calculus courses contributes to science, technology, engineering, and mathematics (STEM) literacy even if many premedical students turn to other than medicine. The practice of medicine and the education of physicians continue to evolve. In 2006, the American Association of Medical Colleges (AAMC) recommended that medical curricula be revised to reflect changes in medical practice and to accommodate the demands of society. These recommendations were developed in response to the AAMC’s May 2006 report, “Building Medical Schools for the 21st Century.” In preparation for its MCAT to be administered in 2015, many colleges of medicine are changing course requirements for students who will begin medical school in 2016 and beyond. Enrollment in college STEM and other courses is expected to shift. Universities may need to provide resources on subjects that will be tested in the revised MCAT. Moreover, disciplines already represented in the MCAT will be expanded by the new committee’s recommendations. For example, because medical research and practice increasingly involves statistics, biostatistics and quantitative methods are becoming more important in premedical education. Premedical students studying neuroscience and other health-related fields should know that biostatistics and behavioral sciences are encouraged to engage in the new MCAT process to provide core concepts to premedical students.

The American Society for Biochemistry and Molecular Biology represents thousands of faculty members who teach and conduct research in departments of biology, chemistry, biochemistry, and molecular biology. We offer four recommendations for restructuring premedical curricula. If these recommendations are adopted, millions of college students will acquire education that will improve biomedical literacy and better prepare students for the field of medicine in this genomic, proteomic, and metabolomic era. Importantly, these recommendations are based on a basic need for more time for students to take classes in social and behavioral science and in the liberal arts, which are necessary for the revised MCAT. For medical practice and for an informed, sensitive citizen.

1. The introductory year of biology should be refreshed. It hasn’t been updated in 20 years of the United States, and molecular biology is taught to refresh critical thinking in introductory biological science, as preparation for the 2015 revised MCAT to be administered in 2015, many colleges of medicine are changing course requirements for students who will begin medical school in 2016 and beyond. Enrollment in college STEM and other courses is expected to shift. Universities may need to provide resources on subjects that will be tested in the revised MCAT. Moreover, disciplines already represented in the MCAT will be expanded by the new committee’s recommendations. For example, because medical research and practice increasingly involves statistics, biostatistics and quantitative methods are becoming more important in premedical education. Premedical students studying neuroscience and other health-related fields should know that biostatistics and behavioral sciences are encouraged to engage in the new MCAT process to provide core concepts to premedical students.

The American Society for Biochemistry and Molecular Biology represents thousands of faculty members who teach and conduct research in departments of biology, chemistry, biochemistry, and molecular biology. We offer four recommendations for restructuring premedical curricula. If these recommendations are adopted, millions of college students will acquire education that will improve biomedical literacy and better prepare students for the field of medicine in this genomic, proteomic, and metabolomic era. Importantly, these recommendations are based on a basic need for more time for students to take classes in social and behavioral science and in the liberal arts, which are necessary for the revised MCAT. For medical practice and for an informed, sensitive citizen.

1. The introductory year of biology should be refreshed. It hasn’t been updated in 20 years of the United States, and molecular biology is taught to refresh critical thinking in introductory biological science, as preparation for the 2015 revised MCAT to be administered in 2015, many colleges of medicine are changing course requirements for students who will begin medical school in 2016 and beyond. Enrollment in college STEM and other courses is expected to shift. Universities may need to provide resources on subjects that will be tested in the revised MCAT. Moreover, disciplines already represented in the MCAT will be expanded by the new committee’s recommendations. For example, because medical research and practice increasingly involves statistics, biostatistics and quantitative methods are becoming more important in premedical education. Premedical students studying neuroscience and other health-related fields should know that biostatistics and behavioral sciences are encouraged to engage in the new MCAT process to provide core concepts to premedical students.

The American Society for Biochemistry and Molecular Biology represents thousands of faculty members who teach and conduct research in departments of biology, chemistry, biochemistry, and molecular biology. We offer four recommendations for restructuring premedical curricula. If these recommendations are adopted, millions of college students will acquire education that will improve biomedical literacy and better prepare students for the field of medicine in this genomic, proteomic, and metabolomic era. Importantly, these recommendations are based on a basic need for more time for students to take classes in social and behavioral science and in the liberal arts, which are necessary for the revised MCAT. For medical practice and for an informed, sensitive citizen.

The American Society for Biochemistry and Molecular Biology represents thousands of faculty members who teach and conduct research in departments of biology, chemistry, biochemistry, and molecular biology. We offer four recommendations for restructuring premedical curricula. If these recommendations are adopted, millions of college students will acquire education that will improve biomedical literacy and better prepare students for the field of medicine in this genomic, proteomic, and metabolomic era. Importantly, these recommendations are based on a basic need for more time for students to take classes in social and behavioral science and in the liberal arts, which are necessary for the revised MCAT. For medical practice and for an informed, sensitive citizen.

The American Society for Biochemistry and Molecular Biology represents thousands of faculty members who teach and conduct research in departments of biology, chemistry, biochemistry, and molecular biology. We offer four recommendations for restructuring premedical curricula. If these recommendations are adopted, millions of college students will acquire education that will improve biomedical literacy and better prepare students for the field of medicine in this genomic, proteomic, and metabolomic era. Importantly, these recommendations are based on a basic need for more time for students to take classes in social and behavioral science and in the liberal arts, which are necessary for the revised MCAT. For medical practice and for an informed, sensitive citizen.

The American Society for Biochemistry and Molecular Biology represents thousands of faculty members who teach and conduct research in departments of biology, chemistry, biochemistry, and molecular biology. We offer four recommendations for restructuring premedical curricula. If these recommendations are adopted, millions of college students will acquire education that will improve biomedical literacy and better prepare students for the field of medicine in this genomic, proteomic, and metabolomic era. Importantly, these recommendations are based on a basic need for more time for students to take classes in social and behavioral science and in the liberal arts, which are necessary for the revised MCAT. For medical practice and for an informed, sensitive citizen.

The American Society for Biochemistry and Molecular Biology represents thousands of faculty members who teach and conduct research in departments of biology, chemistry, biochemistry, and molecular biology. We offer four recommendations for restructuring premedical curricula. If these recommendations are adopted, millions of college students will acquire education that will improve biomedical literacy and better prepare students for the field of medicine in this genomic, proteomic, and metabolomic era. Importantly, these recommendations are based on a basic need for more time for students to take classes in social and behavioral science and in the liberal arts, which are necessary for the revised MCAT. For medical practice and for an informed, sensitive citizen.

The American Society for Biochemistry and Molecular Biology represents thousands of faculty members who teach and conduct research in departments of biology, chemistry, biochemistry, and molecular biology. We offer four recommendations for restructuring premedical curricula. If these recommendations are adopted, millions of college students will acquire education that will improve biomedical literacy and better prepare students for the field of medicine in this genomic, proteomic, and metabolomic era. Importantly, these recommendations are based on a basic need for more time for students to take classes in social and behavioral science and in the liberal arts, which are necessary for the revised MCAT. For medical practice and for an informed, sensitive citizen.

The American Society for Biochemistry and Molecular Biology represents thousands of faculty members who teach and conduct research in departments of biology, chemistry, biochemistry, and molecular biology. We offer four recommendations for restructuring premedical curricula. If these recommendations are adopted, millions of college students will acquire education that will improve biomedical literacy and better prepare students for the field of medicine in this genomic, proteomic, and metabolomic era. Importantly, these recommendations are based on a basic need for more time for students to take classes in social and behavioral science and in the liberal arts, which are necessary for the revised MCAT. For medical practice and for an informed, sensitive citizen.

The American Society for Biochemistry and Molecular Biology represents thousands of faculty members who teach and conduct research in departments of biology, chemistry, biochemistry, and molecular biology. We offer four recommendations for restructuring premedical curricula. If these recommendations are adopted, millions of college students will acquire education that will improve biomedical literacy and better prepare students for the field of medicine in this genomic, proteomic, and metabolomic era. Importantly, these recommendations are based on a basic need for more time for students to take classes in social and behavioral science and in the liberal arts, which are necessary for the revised MCAT. For medical practice and for an informed, sensitive citizen.

The American Society for Biochemistry and Molecular Biology represents thousands of faculty members who teach and conduct research in departments of biology, chemistry, biochemistry, and molecular biology. We offer four recommendations for restructuring premedical curricula. If these recommendations are adopted, millions of college students will acquire education that will improve biomedical literacy and better prepare students for the field of medicine in this genomic, proteomic, and metabolomic era. Importantly, these recommendations are based on a basic need for more time for students to take classes in social and behavioral science and in the liberal arts, which are necessary for the revised MCAT. For medical practice and for an informed, sensitive citizen.

The American Society for Biochemistry and Molecular Biology represents thousands of faculty members who teach and conduct research in departments of biology, chemistry, biochemistry, and molecular biology. We offer four recommendations for restructuring premedical curricula. If these recommendations are adopted, millions of college students will acquire education that will improve biomedical literacy and better prepare students for the field of medicine in this genomic, proteomic, and metabolomic era. Importantly, these recommendations are based on a basic need for more time for students to take classes in social and behavioral science and in the liberal arts, which are necessary for the revised MCAT. For medical practice and for an informed, sensitive citizen.

The American Society for Biochemistry and Molecular Biology represents thousands of faculty members who teach and conduct research in departments of biology, chemistry, biochemistry, and molecular biology. We offer four recommendations for restructuring premedical curricula. If these recommendations are adopted, millions of college students will acquire education that will improve biomedical literacy and better prepare students for the field of medicine in this genomic, proteomic, and metabolomic era. Importantly, these recommendations are based on a basic need for more time for students to take classes in social and behavioral science and in the liberal arts, which are necessary for the revised MCAT. For medical practice and for an informed, sensitive citizen.

The American Society for Biochemistry and Molecular Biology represents thousands of faculty members who teach and conduct research in departments of biology, chemistry, biochemistry, and molecular biology. We offer four recommendations for restructuring premedical curricula. If these recommendations are adopted, millions of college students will acquire education that will improve biomedical literacy and better prepare students for the field of medicine in this genomic, proteomic, and metabolomic era. Importantly, these recommendations are based on a basic need for more time for students to take classes in social and behavioral science and in the liberal arts, which are necessary for the revised MCAT. For medical practice and for an informed, sensitive citizen.
The Bottom Line

• We need to see how MCAT\textsuperscript{2015} is constructed and how it treats the intersection of content and skills in chemistry.

• Regardless of MCAT\textsuperscript{2015}, we should recognize that for most chemistry programs the majority of first- and second-year students have a strong biological interest.
  – Is your program optimally constructed to take this into consideration?
  – Metrics will be needed to determine if any pedagogical changes are meeting the needs of all students.
THANK YOU!