

From College to Clinic: Reasoning Over Memorization Is Key for Understanding Anatomy

SUE ANN MILLER,* WILLIAM PERROTTI, DEE U. SILVERTHORN, ARTHUR F. DALLEY, AND KYLE E. RAREY

Anatomy and physiology are taught in community colleges, liberal arts colleges, universities, and medical schools. The goals of the students vary, but educators in these diverse settings agree that success hinges on learning concepts rather than memorizing facts. In this article, educators from across the postsecondary educational spectrum expand on several points: (1) There is a problem with student perception that anatomy is endless memorization, whereas the ability to manage information and use reasoning to solve problems are ways that professionals work. This misperception causes students to approach the subject with the wrong attitude. (2) The *process of learning* to use information is as important as the concepts themselves. Using understanding to explain and make connections is a more useful long-term lesson than is memorization. Anatomy should be presented and learned as a dynamic basis for problem solving and for application in the practice and delivery of quality health care. (3) Integration of form and function must be explicit and universal across all systems. (4) Using only models, images, audiovisuals, or computers cannot lead students to the requisite reasoning that comes from investigative dissection of real tissue. (5) Some undergraduate courses require students to memorize excessive musculoskeletal detail. (6) Learning tissue biology is a particular struggle for medical students who have no background from an undergraduate course. (7) Medical professors and students see benefits when students have taken undergraduate courses in anatomy, histology, and physiology. If medical schools suggest these electives to applicants, medical students might arrive better prepared and, thus, be able to learn clinical correlations more efficiently in the limited allocated time of medical school curricula. *Anat Rec (New Anat)* 269:69–80, 2002. © 2002 Wiley-Liss, Inc.

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INTRODUCTION

Anatomy and physiology are taught in community colleges, liberal arts col-

leges, universities, and medical schools. Postcourse goals of the students vary, but understanding form and function is a common interest of both teachers

and students. Members of the American Association of Anatomists (AAA) and the Human Anatomy and Physiology Society (HAPS) met for a discussion of what they identified as important concepts that all undergraduates should understand about human anatomy and physiology. The educators work in environments ranging from community colleges to medical schools. Medical educators, on the one hand, want to have students arrive at their schools with specific skills that will facilitate their moving more quickly to the depth needed for clinical practice, whereas educators in other settings face a very real threat of having to justify course topics that curriculum committees view as no longer necessary or as easily relegated to computer-assisted learning programs. Although the context of where anatomy is taught varied among attendees, there was a clear agreement about priorities in teaching anatomy

Dr. Miller, a member of the American Association of Anatomists (AAA), is Professor of Biology at Hamilton College in Clinton, NY, where she teaches courses in anatomy, histology, and embryology. As a member of the AAA Education Affairs Committee, she chaired the Experimental Biology 2001 symposium "Important Concepts That All Undergraduates Should Understand About Human Anatomy and Physiology," from which this article developed. Mr. Perrotti is the President of the Human Anatomy and Physiology Society (HAPS) and Professor in the Life Science Department at Mohawk Valley Community College in Utica, NY. He teaches Human Anatomy and Physiology to first-year college students oriented toward nursing, allied health, and physical education/sports medicine. Dr. Silverthorn is a member of HAPS and chairs the American Physiological Society (APS) Teaching Section. She is the coordinator for undergraduate physiology teaching at the University of Texas-Austin and teaches upper-division physiology in the School of Biological Sciences. She is also the editor of *Advances*

in Physiology Education. Dr. Dalley (of the AAA) is Professor in the Department of Cell Biology, Vanderbilt University School of Medicine. He is Course Director of Medical Gross Anatomy and also teaches courses for physical therapists, residents, house staff, medical school seniors, and continuing medical education (CME) students. Dr. Rarey (of the AAA) is Professor of Anatomy and Assistant Dean for Program Evaluation and Development for medical education at The University of Florida College of Medicine, Gainesville. He teaches clinical human anatomy and human embryology, is Course Director for the first-year medical gross anatomy course, and coordinates the first unit of courses for entering medical students.

*Correspondence to: Sue Ann Miller, Department of Biology, Hamilton College, 198 College Hill Road, Clinton, NY 13323. Fax: 315-859-4807; E-mail: smiller@hamilton.edu

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and about the importance of learning fundamental concepts to enhance student success in clinical fields.

In this article, five educators present short statements about what they see as priorities in teaching anatomy. Their statements will be presented in progression from community college to 4-year college, to university, then to medical schools.

UNDERGRADUATE ANATOMY EDUCATION: THREATS, CHALLENGES, APPROACHES

William Perrotti

A traditional hands-on anatomy laboratory experience is very much in jeopardy in many undergraduate institutions. Contributing to this is a constellation of factors that seem to drain a student's time, energy, and/or motivation and often set the stage for poor performance. This seems especially true in a rigorous lab-based science. Threats to a traditional, hands-on lab experience can be divided into specimen-related, student-related, technology-related, and instruction/instructor-related factors.

Specimen-related factors center on the perceptions of students or administrators. Some argue that dissection and work with biological specimens or tissues are outdated or unnecessary, because there are now so many excellent visual, high-tech alternatives. Some students claim to be disgusted by the smell, the feel, or just the thought of touching dead, preserved specimens. It is difficult to gauge whether these perceptions are manifestations of immaturity, awkwardness in confronting experiences that are foreign to previous life experiences, or evidence of a lack of commitment to or interest in a lab science. Others argue that the use of preserved specimens is not healthy. This may be true if provisions for adequate skin protection and ventilation are lacking.

Administrators often argue that such experiences are unnecessarily expensive. Although it is true that specimens are a continuing expense and that a functional, safe laboratory facility is expensive to construct and to operate, these are necessary ex-

penses for an effective and stimulating educational experience offered only through analysis of preserved specimens and cadavers (for additional discussion, see Aziz et al., 2002). Lastly, some argue against the use of specimens on moral grounds. An educator's response to this must be to ensure that well-planned and effective instructional exercises result from use of specimens.

Today's students are different. Many have multiple responsibilities involving family, employment, or community that consume time, attention, and energy that might otherwise be used for study. Many are returning to school after a hiatus of some length and with a history of academic failure or at least no recent record of confidence-building success. Many, especially younger students, need to be entertained to remain engaged or they lack an academic work ethic. An attitude of "show me" rather than "can do" often prevails.

The technology of today creates for some the view that the world wide web is, or can be, the science laboratory. Virtual experiences often seem (at least in the minds of some students, and even some educators) able to replace or supplant what is real and immediate. A take-home test mentality, in which information must no longer be mastered but merely located and reported, often results. Insights derived from direct interaction with the real world are difficult if not impossible, and often these interactions are viewed as unnecessary or superfluous.

Of critical importance to the success of students are their instructors and the instructional climate they create. Disengaged instructors or those perceived by students as lazy or uninformed instantly neutralize any potential for interest or motivation in students. Inconsistent rigor within a department or between schools sets the stage for a competition in which the ease of achieving a higher grade, rather than the quality of the educational experience, becomes the dominant factor in course selection.

Given this framework, the challenge becomes how to excite students about anatomy. This means making anatomy more than a simple labeling exercise or the rote memorization of a

long list of structural detail. It must bring students to a strong enough grounding in the body plan at both the macroscopic and microscopic levels to support the discussions of function that must follow. This becomes possible if the goal of the anatomy lab experience is to create an exercise in observation, exploration, and discovery. Such an experience of necessity focuses more on the process of discovery and *not* only on the answer.

The mix of students served by the course and the decision to use dissection or prosections or both will to a large degree dictate the specifics of the exercises that are developed. At Mohawk Valley Community College (MVCC) in upstate New York, the college's integrated course sequence in human anatomy and physiology is directed largely at nursing and allied health students but also serves a broader audience that includes science and physical education students. An introductory exploration of the cat by guided dissection, exploration of prosected human cadavers, dissection of selected nonhuman organs, and the examination of several preserved human organs serve as the bases for the lab experience. A successful exploration exercise must guide students through an orderly systematic process of investigation. It must ask questions within the exercise and elicit from students descriptions and comparisons of structures they have observed and evaluated. It should create a series of problems to investigate, analyze, and solve. Instructors in turn must be prepared for a slower pace in which less material is covered than in the traditional identification approach. Instructors must refrain from providing correct answers before students have advanced their own conclusions and observations. This requires a surprising amount of patience.

Certainly this approach requires that students be able to recognize and identify numerous structures, but this is not the primary focus. Much structure identification simply happens in the course of completing various exploration tasks. Examples of some of the specific assignments used in this investigative approach to lab are shown in Box 1 (Drogo and Perrotti, 2001).

BOX 1: Examples of Assignments Used in an Investigative Approach to Anatomy Laboratory at Mohawk Valley Community College

Verify or refute:

- It is possible to make observations about internal viscera without entering a body cavity.
- There is a characteristic pattern of fat distribution in the body of the cat or of the human.
- Some organs or body structures have well-developed elastic properties.
- A general body plan is consistent among individuals, but there are many specific details of anatomy that differ from one individual to another.

Compare two organs or structures or tissues:

- Describe how the stomach and gall bladder are structurally similar.
- Describe how the stomach and gall bladder are structurally different.

Make observations and reach a consensus:

- Trace the small bowel from distal to proximal. Determine whether there is an observable structural difference that distinguishes ileum from jejunum from duodenum.

Analyze anatomical specimens:

- Using selected anatomical landmarks and measurements, determine the likely gender of a skull.

Relate surface anatomy to internal anatomy:

- Using proper terminology and surface landmarks and references, describe the heart's location (right, left, superior, and inferior margins) within the chest.

Synthesize anatomical information:

- Using a varied selection of bones from either side, assemble a single, complete upper or lower extremity.

Verify or analyze clinical techniques and procedures:

- Demonstrate on a partner the Allen Test of collateral circulation to the hand and, using a prosected specimen, demonstrate its anatomical basis.

Evaluation of student performance is more complicated when this investigative, problem-solving method is used. Although traditional quizzing with a focus on structure identification is used, it must be considered only one of several evaluative approaches. To emphasize the importance of the specimen exploration process, the teams of students are observed closely as their investigations progress. The instructor is constantly circulating among them, asking students to describe, explain, and/or demonstrate their findings. This method has

been formalized into a check-off process that is worth grading points. Other elements of the evaluation spectrum include quizzes with a comparison/analysis/application emphasis and formal presentations on assigned aspects of functional anatomy, which are not otherwise addressed in the regular lab sessions.

The effectiveness of this approach to anatomy lab (compared with the traditional lab experience) has not yet been formally evaluated. However, impressions thus far based on anecdotal evidence have been encouraging.

TEACHING HOW TO THINK LIKE AN ANATOMIST: UNDERSTANDING AND SKILLS FOR CONTINUED STUDY

Sue Ann Miller

Courses at small liberal arts colleges must serve students who have a variety of postbaccalaureate goals. Courses on anatomy, cells and tissues, and embryology can address fundamental concepts that will serve students who are interested in health careers, as well as be important to students who plan on entering other careers and who simply have an interest in understanding their own bodies. Here the concepts and skills for learning anatomy are addressed, with an emphasis on *how* educators of undergraduates can more effectively organize these courses.

The ideas in this section evolved from my experiences as a teaching assistant, and more recently a professor, of undergraduate courses in anatomy, cells and tissues, and embryology. Contributions were made through feedback from former students and continuous interaction with colleagues in the AAA. I have always openly discouraged memorization, and I have seen that students learn much better through analysis. Examples of creative approaches to teaching comparative anatomy were presented previously (Miller, 1999) and will not be detailed here.

Table 1 lists some basic concepts and skills that provide a foundation for continued learning. It is important that undergraduate courses include approaches to learning and using information as concepts in addition to the information itself. Skills enable a student to learn better in the short term and to continue learning during a career. Everyone has a body to care for, and everybody is a consumer of health care services.

Concepts

The subject of how cells are organized into tissues and how tissues are organized into organs includes fundamentals of histology, particularly epithelia, connective tissue organization of specialized cells (e.g., muscle, neural), glands, fascia, layers, and organiza-

TABLE 1. Concepts and skills that provide a foundation for continued learning

Concepts	<p>How cells are organized into tissues and how tissues are organized into organs: epithelia; connective tissue relative to specialized cells (e.g. muscle, neural); fascia, layers and body tubes</p> <p>Integration of form with function</p> <p>Thoughtful dissection is a way of learning</p> <p>Understanding is more important than memorization</p>	<p>Support: hydrostatic, connective tissue, musculoskeletal</p> <p>Locomotion: lever arms, energy (physics)</p> <p>Exchange and diffusion</p> <p>Interrelation of organization and environment (terrestrial, aquatic, etc.)</p>
Skills	<p>Ability to think dynamically across levels of organization</p> <p>Ability to draw selectively on specific information</p> <p>Awareness of word roots</p>	

tion of body tubes. If students can see universal aspects of organization, they can begin to think reasonably about the identity of a tissue or organ when confronted with a specimen they have not seen before.

Integration of form with function includes support, locomotion, and exchange. Discussion should be a thoughtful analysis of organization instead of lists of parts. Considering support and locomotion encourages awareness of the physics of form and function. The lever arms within musculoskeletal units can be related to walking and cycling (gears). Arrangements for bipedal locomotion can be compared and contrasted with adaptations for running and digging. These are interesting situations that capture student interest. If there is time, brief discussions of arrangements for swimming, flying, saltation, and the varied abilities of snakes add additional interest. Several texts provide ample resources for this approach to functional morphology (e.g., Hildebrand and Goslow, 2001; Liem, et al., 2001; Kardong, 2002). Students do not need to memorize minutia of origins and insertions to understand support and locomotion, but they will learn, almost passively, many musculoskeletal terms during these considerations. Exchange addresses the relationship of arrangements to facilitation of functions. An example is the limitations that organization places on flow and diffusion. If students appreciate the fundamental interaction of form and function in exchange, then their energy can be more produc-

tively directed to the abundant molecular detail that will be presented in subsequent study.

Addressing potential interaction of systems on the basis of structural organization sets up appropriate thinking for such subjects as physiology and pharmacology. This approach is a more interesting way to discuss roles of integument and derivatives and the internal systems, than to simply allow students to memorize parts. Interrelation of organization and environment is another aspect of functional morphology that encourages students to make connections. Locomotion, diet, and environment (terrestrial or aquatic) all affect and support lifestyle. Challenges of comparison in an undergraduate course provide breadth of examples while they set up skills for subsequent learning.

Thoughtful dissection is understood by anatomists to be a tool for understanding, but students typically do not expect that experience. If undergraduate students dissected anything in secondary school, they probably only learned to name it and cut it out. Students have not learned to observe and to think and to use the elements of the structure to lead the teasing apart of form. Thoughtful dissection is a concept that must be taught as a way to learn.

Similarly, the reality that memorization is not understanding is a concept that must be repeatedly emphasized in undergraduate courses. Students might already accept that understanding cells and tissues is essential to understanding anatomy and

physiology, but students typically do not realize that information is only part of the goal. Professionals must be able to *use* information, so it is important to make it clear to students that ability to reason outlasts memorized information. Having reasons for a task facilitates understanding, so it helps to give students reasons *why* an approach of reasoning is better and *why* memorizing is not the same as understanding. This is part of my class discussion, and I supplement that with information on Web pages (Miller, 2001).

Skills

The *process of learning* how to address concepts is as important as learning the concepts themselves. Essential skills that will support learning are also listed in Table 1. Dissection is clearly also a skill, but I chose to list it as a concept here to emphasize the

The process of learning how to address concepts is as important as learning the concepts themselves.

importance of the thought that accompanies real dissection.

1. Ability to think across levels of organization ranges from the level of cells (if not molecules) up to organs, regions, and whole organisms. This includes ability to visualize three-dimensional form from word descriptions and from two-dimensional diagrams. These mental skills are an important component of spatial imaging that is so fundamental to use of anatomical and physiological information.
2. Ability to draw selectively on specific information is the skill to manage a reservoir of mental storage and to select only what is appropriate to the need at hand. This is a skill for testing, and a skill for functioning in any technical career.
3. Awareness of word roots is a basic language skill in health and science

BOX 2: Examples of Questions That Require Analytical Thinking and That Show Understanding

- What arrangement of fibers would you expect in most limb muscles and why? (Gets at pennate for power and packing, not strap or sheet)
- What would you expect the predominate fiber type to be in pectoral muscles of a migratory bird and why? (Need for endurance suggests dark meat which suggests slow twitch, etc.)
- Is the mature structure of a bone we call endochondral truly endochondral? (Gets at deposition of bone matrix vs categories of bones)
- How do the physical limits of diffusion impact organization of biological structure?
- Where and how does a chick embryo get calcium to build a skeleton?

professions that gives students tools they need to find understanding in new information.

Teaching and Rewarding Reasoning

Anatomists think about tissues as organized collections of cells and cell products that have functional physical and chemical components, but students expect to memorize parts or processes. This misperception must be considered in designing any anatomy course. Anatomists think about *how* and *why*, yet students do not naturally integrate form with function. If we want students to think as anatomists do, then we must encourage and reward that approach by the ways we teach.

Investigative thinking is encouraged if the professor asks students about situations rather than telling them information outright (as in most lectures). This approach is time-intensive, so it is not practical to structure an entire course that way, but such experiences are important for students.

Inquiry-based analysis is a good way to help students learn the process as they acquire understanding. It encourages integration and thoughtful analysis. Clinical case studies have been used in medical teaching for decades, and the concept has now been expanded to include stories in broad context and from current events. These can be a good means for getting students to teach themselves while the instructor guides the experience. Web sources for these sorts of case studies (e.g., the National Center for Case

Study Teaching in Science 2001) include some that are appropriate for these undergraduate courses. Using this approach also initiates students in a learning style they might encounter in medical school and will use in most careers.

Group work becomes a form of peer teaching that facilitates the desired learning styles in addition to learning of concepts. Case studies or problem-based learning (PBL) can be done as group work. Group presentations to classmates add a dimension in using knowledge that prepares students to present information to patients, clients, coworkers, or customers.

Assessment teaches, too. Exam format can reinforce misunderstanding of course goals if it does not encourage ability to think and to use information. Unknowns reinforce the skills and students' awareness that they have indeed acquired new abilities to use information. A "name this" format of practical exams suggests memorization to students. Asking *about* something is an indirect way of asking what it is while encouraging reasoning. Questions can present clinical situations that teach as they test students' understanding as well as their knowledge of parts. Multiple-guess exams are easier to grade, but they are difficult to write well, and they also suggest that knowing the "right answer in advance" is what is expected when using understanding to explain and make connections is the more useful long-term lesson for students. Examples of questions that require analytical thinking and that show understanding are shown in Box 2.

Finally, specimens do not have to be human for students to accomplish the desired goals at an undergraduate level. *Organization* of other vertebrates can be used to address fundamentals while it gives perspective and exposure to phylogenetic diversity. Comparative anatomy should not be taught as an exercise in memorizing parts and taxonomy. Furthermore, use of a cat, rabbit, mink, or fetal pig for learning fundamentals can help avoid subsequent assumption that students already know it all. This complements and does not conflict with subsequent medical priorities, while it develops skills and prepares students to move on in learning how to use their understanding in the context of a health profession.

In summary, concepts, approach, and understanding are all important. Good general goals include teaching something about the integration of

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structure and function while making it clear there is always more to learn. We must make it clear that skills are being developed and that skills are as important as information. To encourage the desired skills and approach, the design and conduct of a course and the examinations must encourage application of analytical thinking and reasoning by providing opportunities for students to use information and to demonstrate understanding. However it is done, it must be made clear to students that understanding is the goal and that memorizing is not understanding.

HOW MUCH ANATOMY DO UNDERGRADUATES NEED?

Dee U. Silverthorn

Integration of physiology with anatomical form and function in under-

BOX 3: Goals Desired by Faculty Teaching A&P Courses

Compiled from a 1996 survey of HAPS members listed in order of decreasing importance

- Develop thinking, reasoning, data-handling and interpretation skills
- Apply learning to realistic situations
- Learn and apply the scientific method
- Use homeostasis and control as an integrating theme
- Integrate information across systems
- Develop the ability to think in three dimensions
- Relate form and function
- Understand development
- Prepare for qualifying examinations.

graduate anatomy and physiology (A&P) courses is currently being debated. We have come to recognize that what and how we teach in A&P does not necessarily correspond with the content and skills that we think are most important for our students. In light of this finding, the HAPS Course, Curriculum, and Assessment Committee has, therefore, undertaken to revise the HAPS curriculum guidelines for A&P courses. Co-chairs of the HAPS committee, Dan Lemons and Joe Griswold, spearheaded the effort.

As part of the information-gathering process, Lemons and Griswold ran workshops at several annual HAPS meetings. Faculty participants in 1996 were asked to rank goals of their anatomy and physiology classes. The compiled results are listed in Box 3.

The same faculty ranked the highest priority body systems as (1) nervous system, (2) cardiovascular system, (3) fluid, electrolyte, and acid-base balance, (4) immune system, (5) respiratory system, (6) endocrine function, and (7) musculoskeletal system. Notice that the musculoskeletal system, which is the focus of most undergraduate A&P books, was ranked last (for more detail on the workshops and the results, see Lemons and Griswold, 1998).

The following year (1997) at a regional HAPS meeting in New Orleans, directors from nursing, radiology technology, and respiratory therapy programs participated in a panel on "Is the A&P we're teaching what the professional schools want?" They all came to the same conclusion: teach less anatomical detail. This initiated a lively discussion among the partici-

pants of "why most A&P courses include so much anatomy." The faculty said "But that's the way the books do it." Indeed, the major A&P texts have a third to half of the text devoted to the musculoskeletal system. The faculty also said, "There are not any other books to teach it any other way." In defense, an editor from one of the major publishers said, "But there has been no demand from faculty to do the books any other way." This defines the second issue: Traditional A&P textbooks match the way we teach now, not the way we would like to teach.

We have been dealing with this dilemma as we redesign our A&P curriculum at the University of Texas at Austin. This revision was prompted by complaints from our Nursing School that the students were not well-prepared for their pathophysiology class and by a request to bring our courses in line with those at other state institutions so that students could transfer credits more easily. The old curriculum consisted of separate anatomy and physiology classes: a three-credit mammalian anatomy course with two lecture and three laboratory hours per week, a three-credit human physiology lecture class, and a one-credit, 3-h physiology laboratory class. Students were not required to take the courses in any particular sequence. The combined courses only totaled 7 credit hours, which did not comply with the 8 credit hours of A&P required by various professional schools.

Our new course, started in fall 2000, consists of a two-semester sequence with 4 credits each semester. Each semester consists of three lecture hours, one tutorial discussion hour, and three

laboratory hours per week. The course is called "Physiology and Functional Anatomy," to emphasize the change in focus from a traditional A&P class. The lectures are organized like those of a physiology course but with more functional anatomy brought in where appropriate. The textbook for the lecture is a traditional human physiology textbook. Handouts supplement material on the musculoskeletal system.

Most of the anatomy is done in the laboratory. We discarded the rabbit dissection that was a focus in the old anatomy class. Students now use human models and preserved organs such as sheep heart, kidneys, and eyes. Instead of having the students memorize fifty origins, insertions, and actions, we are using biomechanical arm and leg models and curriculum developed by Lemons and Griswold (available through Denoyer-Geppert, 1-800-621-1014). The students have an in-house laboratory manual that we have been writing as the course develops. We have been using clinical anatomy books for guidance, such as Ellis (1973) Passmore and Robson (1971), and Snell (1973). In designing the new lab experiences, we have been placing the emphasis on understanding concepts rather than on memorization of trivia that students will never encounter in their clinical experience.

The key issue that remains unresolved is the assessment of the new approach. We have now completed one full year of the course and have subjective information that supports our goal of developing students who are willing to be independent learners and problem-solvers. The teaching materials for the class are still under development, however, and we are postponing extensive assessment of the curriculum until those materials are finalized. In general, we are very pleased with the change in our teaching approach and plan to continue it.

ANATOMY: EXERCISE IN MEMORIZATION, OR A DYNAMIC APPLIED SCIENCE? AN APPEAL FOR THE INTEGRATION OF CONCEPTS

Arthur F. Dalley

As an anatomist, I am concerned that my science—our field of work and

study—is perceived by many as static—even “dead”. I want to see anatomy represented and received in the best possible light—as something which is not primarily an obstacle or an ominous means of screening candidates for various careers, but something that is *useful* and has sufficient value that it will continue to exist as a subject worthy of study and as a field that a few (hopefully very talented) individuals find sufficiently interesting that they actually select it for the *focus* of their careers as teachers or researchers.

As a teacher of anatomy for practitioners of the health sciences, it is my impression that most students who complete an undergraduate experience that includes a course in anatomy and physiology believe that anatomy is primarily *about* the recognition and naming of structures, often on bare skeletons, or on isolated bones or organs (terminology). Anatomy is typically recalled by former students as involving rote memorization of endless lists and tables of terms. All-night study binges often involved such contrivances as flash cards, reproduced tables, and mnemonic devices. Professional training is thus entered with the assumption that the required anatomy course will involve more of the same (perhaps with the addition of a less than pleasant encounter with the dead), and it is approached accordingly. Professional school anatomy instructors must expend much effort trying to dissuade students of this preconception. We encourage them to *reason* their responses by recalling *mental images of structure they have observed* rather than by regurgitating facts crammed into short-term memories during last-minute studying.

Although anatomy necessarily *involves* the learning of many terms (indeed, it is the basic language of medicine), the terms are *not* in themselves the goal, any more than the learning of any language is about the individual words. The *purpose* of language is communication—the accurate and meaningful conveying of information. This is also true about that important *aspect of anatomy* that involves terminology. The new international standard for anatomical terminology, *Terminologia Anatomica* (Federative Committee on Anatomical Terminol-

ogy, 1998; reviewed by Whitmore, 1999) is an inexpensive collection of user-friendly anglicized terminology that also includes the classic, Latinized forms. Using this terminology, which is based on logic and reason more than tradition, will be advantageous to all who make the effort to use it. It will also be greatly advantageous if, some day, all anatomy is spoken in the same “dialect.” That information will be best assimilated if the terms and facts are put into a context of function or application, and then its usefulness will be made apparent. Instead, we tend to pile on the terminology and relationships without meaning. When the meaning is learned later, no link is made that acknowledges the role of the more fundamental learning.

Although anatomy is perceived as being about the memorization of terms identifying structures of ever-

Anatomy is a working science for problem solving and application in the practice and delivery of quality health care.

increasing triviality, the true *purpose* of anatomy is to recognize normal structure and to realize its role in producing normal function, i.e., to appreciate interdependence of form and function. Anatomy is the basis for understanding normal function; for being able to recognize how normal function may be effected when the anatomy has been altered as the result of developmental defect, disease, or trauma; and for determining how normal or near normal function might be restored. In other words, anatomy is a basis for logic and reasoning, deduction, and problem solving. It is my perception that very few of us are doing a very good job of making the true purpose of anatomy sufficiently evident that it is even recognized. Anatomy courses in medical schools likewise commonly fail to portray the purpose of anatomy. I have on several occasions been told by surgeons that

they “don’t remember any anatomy,” when I know they practice the application of anatomy meticulously and continuously. In saying this, they are revealing that they, too, remember anatomy as being about a specific set of terms, and they are admitting that outside of those used in their subspecialty, most of those terms are forgotten. They fail to recognize their knowledge of structure and its role in normal function as being anatomy, which has actually become second nature to them, like reading or arithmetic. They seem to think their knowledge was intrinsic. They may or—sadly enough—may not have learned it from an anatomy course.

No place should be more suited for establishing the correct view of anatomy than a course that integrates anatomy and physiology. Unfortunately, such courses often bear this title to describe a disciplinary sequence within the course rather than the integration of concepts throughout the course.

It would be ideal for all undergraduate students to complete their experiences with an understanding of basic *anatomical concepts* at the expense of memorizing the names (and yes, even the origins, insertions, and individual innervation) of as many structures as possible. These concepts are relatively simple and basic, and they are covered in the introductory chapters of the textbooks. Often we take them for granted, forgetting what it is like not to know, so we fail to cover them at all. Examples of such concepts are listed in Box 4.

The concept of “normal” is particularly important. It is a concept that students who have learned anatomy without the benefit of dissection almost always fail to appreciate. That is, that “normal” in anatomy means the most common variation, and that because of the large number of variations within the normal range, that which is depicted as “normal” may in fact be present less than half the time! I could not find the term “variation” in the indexes of any of the undergraduate anatomy texts I searched.

I would also recommend having students attempt the following exercise in morphology. First, have students view a three-dimensional object with several components, then, re-

BOX 4: Examples of Basic Anatomical Concepts Worth Learning in the Place of Rote Memorization of Terms

- the layered and segmental organization of our bodies
- group muscle dynamics: synergism, antagonism, isotonic/concentric, isometric and eccentric contraction, etc.) and their organization into functional compartments in the limbs
- joint function and motion as a consequence of structure
- the effect of denervation on movement and normal resting position
- the interaction of muscle, fascia and valved vessels in venous and lymphatic return
- understanding what lymph is and how it is produced
- the concept of functional (synovial) potential spaces (e.g., peritoneal, pleural, articular, tendinous, bursal)
- clarification of the distinction between nerves and the various nerve fibers and fiber types they convey
- viewing sectioned material and extrapolating three-dimensional structure from two-dimensional images or serial sections, etc.
- the concept of “normal”

quire them to describe that structure and the relationship of its components to someone else with words. The description should include anatomical terms of description and relationship, and be composed sufficiently well that the other party can form a vision of—or even draw—the object.

Such concepts may result in a “deep” appreciation of anatomy. A course that aims at covering the entire body, or all of its systems by doing so on a superficial “survey” level combined with the forced memorization of lots of terms and isolated facts usually yields disappointing appreciation and transient “knowledge.” Few students will attain this deeper understanding on their own, even if it has been “mentioned” to them and is available in their textbooks, if a special effort is not made to emphasize concepts in our lectures and instruction, and then to examine in a way that requires demonstration of those concepts. Instead, they will opt to fall back on rote memory and hope for the best in examinations.

In summary, it is my opinion that all undergraduate students should learn that anatomy—rather than a monstrous exercise in taxonomy and etymology that is a prerequisite obstacle to a professional degree—is a working science for problem solving and application in the practice and delivery of quality health care.

There are data to support assertions for change in approach and content. Compelling evidence is presented in this final installment.

PREREQUISITE KNOWLEDGE OF ANATOMY AND PHYSIOLOGY FOR ENTERING MEDICAL STUDENTS

Kyle E. Rarey

In most medical schools, the initial curriculum focuses on the normal structure and function of the human body in the context of clinically relevant concepts and principles of human diseases and injuries (Table 2). Medical students who had undergraduate courses in human anatomy and physiology appear to adjust more easily to the intense medical curriculum and appear to learn clinical correlations more efficiently in the initial, limited allocated time of medical school. Importantly, they have the basic terminology upon which to further build their anatomical and physiological knowledge. As in other areas of knowledge, it is easier to build on a foundation of fundamental knowledge of human anatomy and physiology than it is to create concomitantly a foundation and learn medically relevant concepts and principles.

Prerequisite science courses during a student’s undergraduate education are considered essential not only in

determining one’s ability to do well in similar higher level courses but also to ground an undergraduate student in basic, elementary scientific concepts and principles. At the University of Florida College of Medicine, representative of other medical colleges, 32 h of science courses (8 h of general chemistry, 4 h of organic chemistry, 8 h of general biology, 8 h of physics, and 4 h of biochemistry) are prerequisites to be considered as an applicant to medical school.

Undergraduate anatomy and physiology educators adequately prepare students to matriculate into medical school, but histology (tissue biology) is one area that students struggle initially in learning. First-year students labor to learn how cells work to create functioning units of tissues within given organ systems. Anatomy is a visual science. A prior ability to distinguish individual cells and tissues of given organ systems enhances the ability of first-year medical students to learn clinically relevant information about organ systems. Based upon anecdotal observations as an anatomy professor for more than 25 years and data from the American Association of Medical Colleges (AAMC) Graduation Survey, the premise of this article is that undergraduate courses in histology would enhance the initial learning of normal human anatomy and physiology in a first-year medical curriculum.

Surveys of Graduates

Data from surveys of graduating seniors from the University of Florida College of Medicine (classes of 1998, 1999, and 2000) and US graduating classes of 2000 make the following relevant points. When medical students at the University of Florida College of Medicine assessed their first-year curriculum at the end of their first year, 90% of them indicated that they did not have histology (Figure 1). In contrast, 73% of them had enrolled in undergraduate comparative anatomy and 54% had enrolled in physiology. Furthermore, 48% of the students believed that cell biology and 41% of students believed that physiology were valuable premedical courses.

When asked which of the following courses were important in preparing

TABLE 2. Schematic of the first-year curriculum at the University of Florida College of Medicine

Integrated instruction in Human anatomy Radiology Cell and tissue biology Essentials of Patient Care ^a	Preceptor Program (AHEC)*	Neuroscience	Medical physiology Medical genetics Biochemistry and molecular biology of disease Human behavior
		Essentials of Patient Care ^a	

^aEssentials of Patient Care is a sequence of Basic Clinical Skills, Keeping Families Healthy, Ethics, and the Preceptor Program.

them for medical school, more than a third of graduating seniors surveyed stated comparative anatomy (Figure 2), approximately half of the graduating seniors stated biochemistry (Figure 3), and approximately three quarters stated physiology (Figure 4).

Finally, when US graduating seniors were asked about the medical courses in gross anatomy, microanatomy (histology), and physiology, only 17% of the students rated histology as

excellent compared with 42% rated gross anatomy and 43% rated physiology as excellent, respectively (Figure 5).

DISCUSSION

A review of data from surveys of first- and fourth-year medical students at the University of Florida College of Medicine and data from the AAMC 2000 Graduation Survey of all US

graduating seniors indicates that a great percentage of medical students have not had histology during their undergraduate studies. In addition, medical students find greater relevancy for gross anatomy and physiology with their clinical experiences than with cell and tissue biology. On the basis of these data, it seems reasonable to conclude that prior knowledge of histology would facilitate the transition of learning by first-year

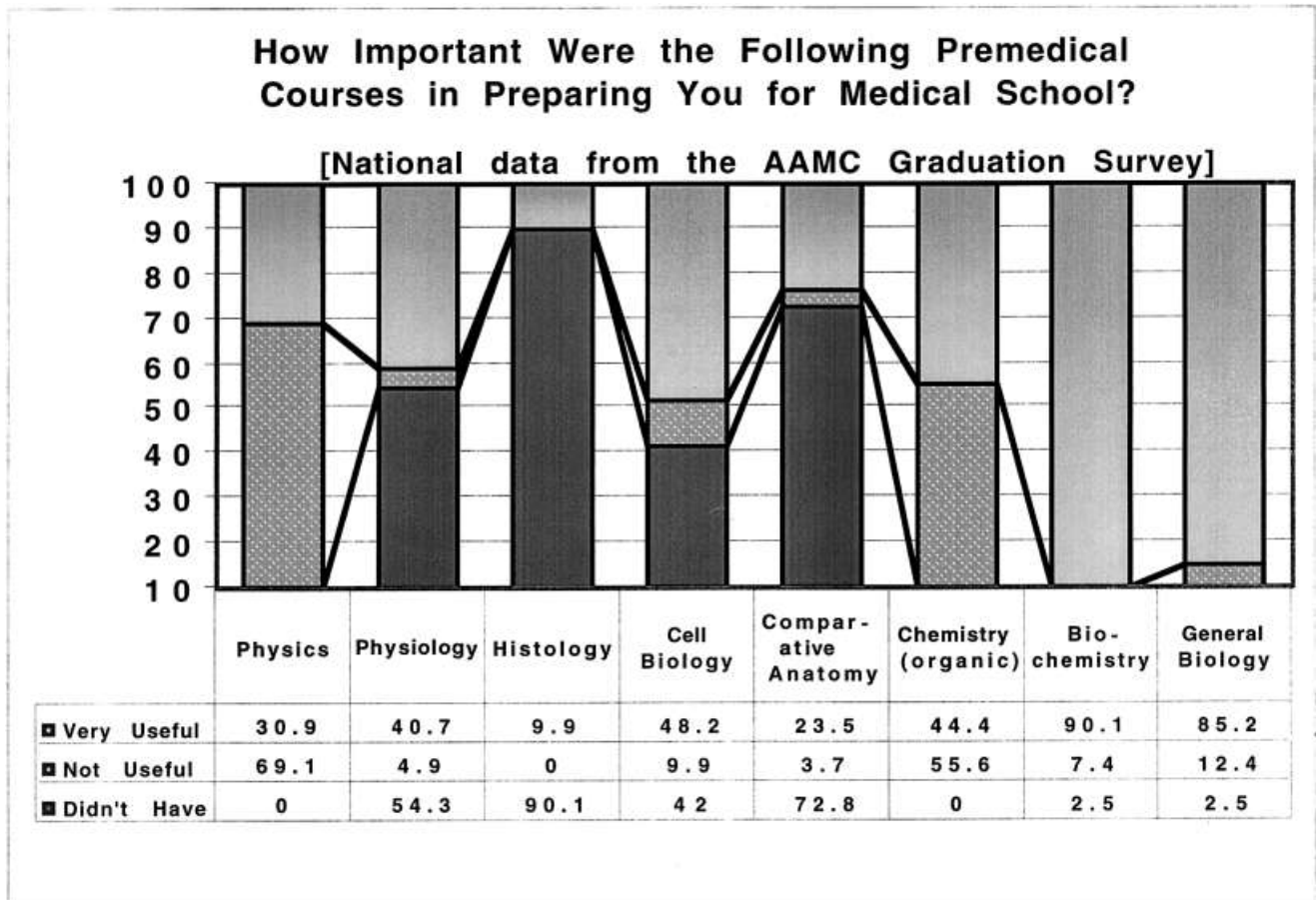


Figure 1. Response to the question, How important were the following premedical courses in preparing you for medical school? Source: AAMC 2000 Graduation Survey.

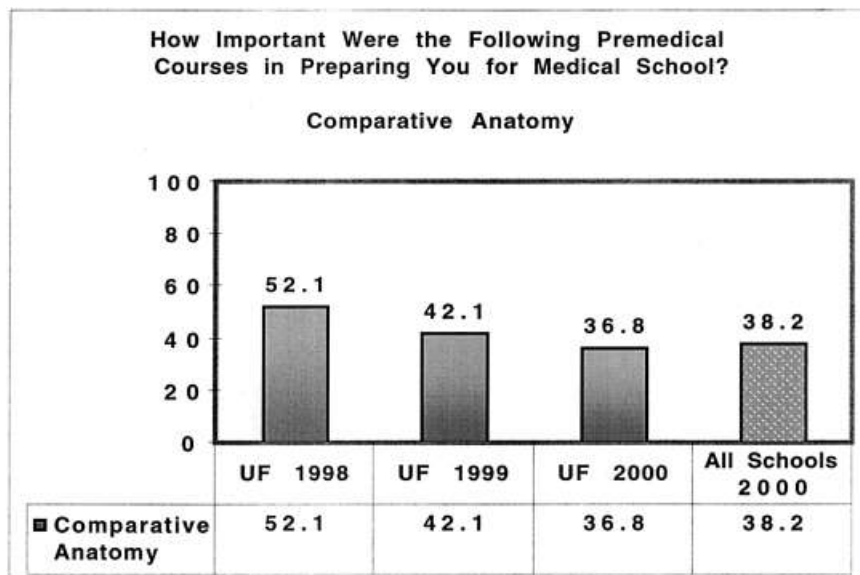


Figure 2. Students' assessment of the importance of a premedical course in comparative anatomy in preparing them for medical school. UF = Univ. of Fl. Source: AAMC 2000 Graduation Survey.

medical students from an undergraduate curriculum to a medical curriculum.

The question is who is responsible for requiring entering medical students to have enrolled in undergraduate courses in histology and/or tissue biology. By way of analogy, medical schools in recent years made an undergraduate course in biochemistry prerequisite, because of the difficulty in teaching medical biochemistry to first-year classes that were composed of students who had and did not have an undergraduate biochemistry course.

Although not advocating that medical students take undergraduate anatomy-physiology related courses, enrollment in them is encouraged. With the available resources on CD-ROM and the Internet, undergraduate students should have the knowledge and skill to distinguish between different cell types and tissues. Such knowledge would enhance an entering medical student during their first-year studies about the normal structure of the human body.

SUMMARY

Information and the skill of managing information are always important in understanding complex subjects. However, students' perception of anatomy is that it is an endless exercise of memorization. This perception

might be the result of experience in precollege courses, traditions embedded in an uninformed grapevine, or it could simply be naiveté. Regardless of the cause, perception must be taken into account in the way that subjects are taught in undergraduate courses.

The process of learning how to address the concepts is as important as the concepts themselves. Learning how to learn and using understanding

to explain and make connections are more useful long-term lessons than is memorization. Anatomy should be presented and learned as a dynamic basis for problem solving and for application in the practice and delivery of quality health care. Integration of form and function must be explicit and universal across all systems. Using only models, images, audiovisuals, or computers cannot lead students to the requisite reasoning that comes from investigative dissection of real tissue. Comparative anatomy should not be taught as an exercise in memorizing parts and taxonomy. Using an inquiry-based approach to functional morphology teaches skills that will be useful to future medical students while conveying an understanding that is interesting to all students. Mental and spatial imaging are important skills for understanding and applying understanding of anatomy. Undergraduate courses that develop these skills (e.g., histology, embryology) will facilitate study of clinical applications of anatomy and physiology.

A prior ability to distinguish individual cells and tissues of given organ systems enhances a first-year medical student's learning of clinically relevant information about organ systems. This finding suggests that undergraduate histology courses, or just

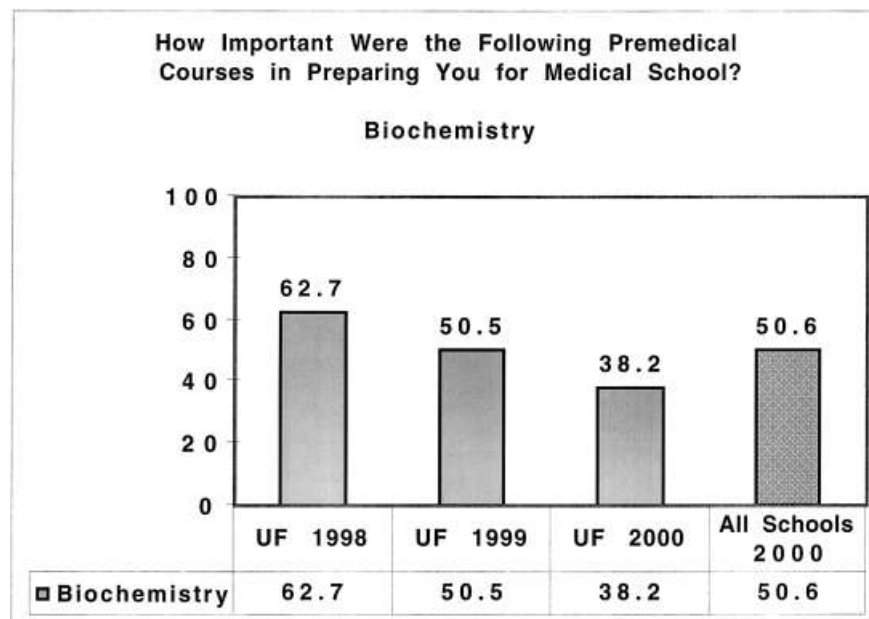


Figure 3. Students' assessment of the importance of a premedical course in comparative anatomy in preparing them for medical school. UF = Univ. of Fl. Source: AAMC 2000 Graduation Survey.

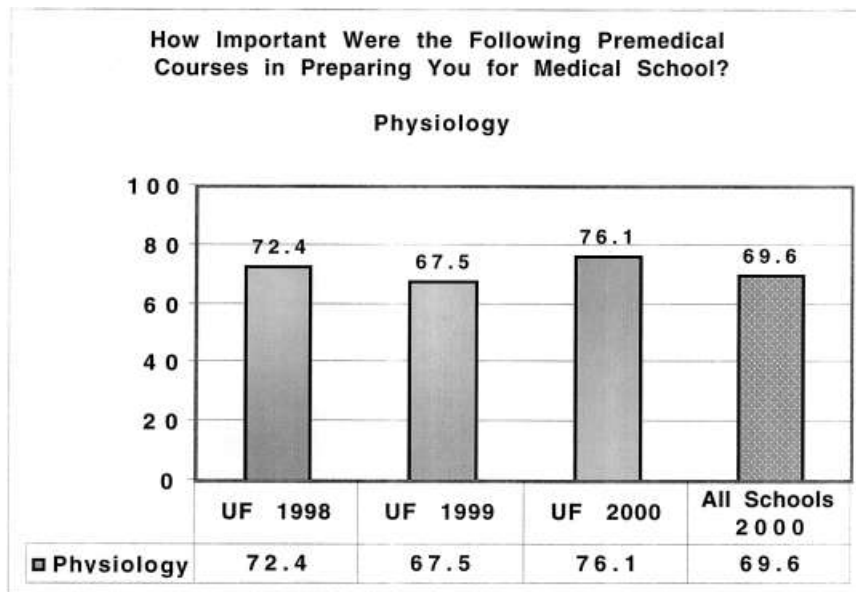


Figure 4. Students' assessment of the importance of a premedical course in comparative anatomy in preparing them for medical school. UF = Univ. of Fl. Source: AAMC 2000 Graduation Survey.

an increase in the histology component of anatomy courses, would enhance the initial learning of normal human anatomy and physiology in a first-year medical curriculum. However, undergraduate curricula do not always include material that the AAMC surveys suggest are useful background for a first-year medical curriculum. When students arrive at medical school without sufficient preparation, is it because courses were not available, or because students did not take what was available? Anatomy and histology courses were dropped from the curricula of many colleges and universities as more molecular demands were made upon course lists. Histology fundamentals are not necessarily a component of modern cell biology courses. Ninety percent of respondents in the AAMC Graduation Survey (Figure 2) said they did not have a premedical histology course. Seventy-three percent of the same respondents did not have a premedical comparative anatomy course, and 54% did not take an undergraduate physiology course. When students responded to those questions on the survey, were they saying the course was not available or that they simply chose not to take it? Either way, medical schools can influence the preparation of premedical students.

IMPLICATIONS

This discussion of concepts and curriculum has implications for medical admissions requirements and consequently for undergraduate curricula. Furthermore, each curriculum influences the other. Under current arrangements, it is probable that students arrive at medical school without

the common background that medical educators assume from their own experience.

Data from AAMC surveys show that students perceive benefit from having taken courses in anatomy, histology (cells and tissues), and physiology as undergraduates, but these courses are not universally required for entering medical school. Students might define benefit as simply giving them a preview of some material so that they can give less attention to that material in medical school. Medical faculty cite a more compelling benefit: students who arrive at medical school with a solid understanding of organismal structure and function and cell and tissue fundamentals are able to address the medical issues related to those subjects, whereas less prepared students spend time and mental energy just coming up to speed on the basics.

These are compelling reasons for medical schools to suggest more directly, in the Medical School Admissions Requirements (MSAR) and elsewhere, that premedical students take electives such as anatomy, cells and tissues, and physiology. Admission circumstances of medical schools vary, but there is a universal interest in obtaining the best students possible

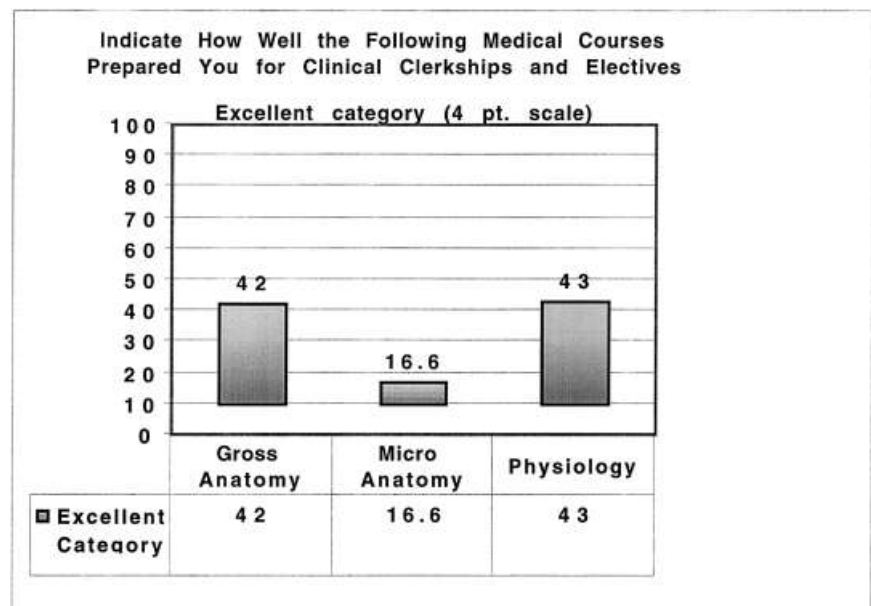


Figure 5. Response to the question of how well medical courses in gross anatomy, microscopic anatomy (histology), and physiology prepared students for third- and fourth-year clerkships and electives, respectively. Source: AAMC 2000 Graduation Survey.

in each entering class. Undergraduate students and advisors pay attention to statements in the MSAR. If such recommended courses exist at the various colleges and universities, students can consider taking them as electives or in summer school. If such courses are unavailable, a clear statement of their value for post-undergraduate study might influence undergraduate curriculum changes. Everyone has an interest in having the best physicians possible. Better integration of curricular priorities across all levels of academic preparation of physicians would assist efforts to achieve this goal.

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