An agenda for research on teaching of physiology

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PHYSIOLOGY IS A DIFFICULT SUBJECT for many medical students, in part because mastery of the discipline requires not only learning (i.e., memorizing) a large number of new terms, facts, and concepts but also considerable problem-solving ability. As teachers we do a better job of teaching the facts of physiology than we do teaching problem solving (19). Traditionally, physiology has employed small-group tutorial sessions and laboratories as vehicles for acquiring problem-solving skills (24, 29) and, although problems may be solved in these sessions, it is rare for any explicit teaching of problem solving to occur (14). Computer-assisted instruction involving simulations offers a contemporary approach to assisting students to integrate their facts and develop problem-solving skills (16, 18, 19), but only limited software is available and relatively few medical schools have the resources to support widespread development and use of this technology (29).

The General Professional Education of the Physician (GPEP) report of the Association of American Medical Colleges (3), the most recent comprehensive evaluation of the state of American medical education, has made many of the same points about medical education in general. The panel that produced it examined the educational system from the baccalaureate level through graduate medical education and generated a set of 27 recommendations. If implemented, these recommendations would result in a major restructuring of the entire continuum of medical education.

At least 9 of the 27 recommendations pertain, directly or indirectly, to the teaching of the basic biomedical sciences. Yet a recent examination of the responses of physiology departments to the GPRP report (20) leads one to conclude that little or nothing has been done, or is likely to be done in the near term, to alter the teaching of physiology.

There are many reasons for this inactivity, but it is most important to recognize that however cogent the GPEP criticisms and however appropriate its recommendations, we—physiology teachers—do not know how to accomplish many of the changes that have been called for. This ignorance is not the result of faculty indifference toward teaching but reflects the current state of the art in the field of science education (15).

I would like to propose here an agenda for research into the teaching of physiology, research the results of which are required if we are to respond in an effective manner to the charge placed before us by the GPEP report. Such research will have to be carried out by educational psychologists, cognitive scientists, and, hopefully, at least a few physiologists.

However, I want to first briefly review some recent findings about expertise and how we might more effectively teach it in physiology.

EXPERTISE: SOME PROPOSITIONS FROM COGNITIVE SCIENCE LITERATURE

Cognitive science is an interdisciplinary field that seeks to study the acquisition and use of knowledge. It has drawn its experimental approaches and theoretical constructs from such disciplines as psychology, linguistics, and computer science and artificial intelligence. Historically, one of the major themes pursued by cognitive scientists has been problem solving and the nature of expertise (in what ways does the expert differ from the novice). Cognitive science has sought to develop formal (objective and rigorous) descriptions of cognitive processes that can be compared with empirical data about human performance and that can be modeled on the computer. It is beginning to provide descriptions of and prescriptions for teaching and learning science (1, 4, 6, 14, 26). Gardner (10) has provided a particularly readable but comprehensive historical review of this field.

Here are some of the findings from cognitive science studies that are relevant to teaching and learning physiology.

Reading a text with comprehension (13)—learning new subject matter—and constructing one’s understanding of a phenomenon (26) are processes that depend for success on the possession of knowledge; in other words, you have to know something to learn something (28). Expertise in a particular domain, i.e., a high order of ability to solve problems, exhibits a large domain-specific component, although there are some general problem-solving skills involved (4, 9, 25); an expert in endocrinology is not necessarily an expert in cardiovascular...
physiology. This is in part true, because expertise is dependent on possessing a sufficiently large and appropriately structured knowledge base in the domain (6).

New information can be presented in a way that helps to structure the student's knowledge base so as to facilitate the development of expertise (30). Furthermore, students can be explicitly taught the components of the problem-solving process (9) and the metacognitive skills (7) that are required for expertise. However, to do this, we must be able to rigorously define the problem-solving process to be carried out and the knowledge base that is required (11).

Acquiring expertise in problem solving requires learning the component problem-solving skills (problem formulation or representation, hypothesis generation, qualitative modeling, pattern recognition, etc.; see Ref. 9), practicing these skills with carefully selected problems (including practicing thinking about one's problem-solving process—metacognition), and appropriate reinforcement of all aspects of performance. How to achieve these steps in the classroom, for a particular discipline or subject matter, is, however, an as yet largely unanswered question.

**GPEP RECOMMENDATIONS**

In considering the applicability of the GPEP recommendations (3) to the teaching of physiology, I would like to consider three periods during the course of medical education: 1) the period of undergraduate education and preparation for admission into medical school; 2) the preclinical years in which physiology is taught; and 3) the period of clinical training beginning with the third and fourth years of medical school and extending through postgraduate medical training. The GPEP recommendations have something to say about each of these periods, although not in any strict chronological order (relevant excerpts from the GPEP recommendations can be found in the APPENDIX).

To begin at the beginning ... The GPEP report calls for a broadening of the nature and level of baccalaureate preparation to be required for admission to medical school (Conclusion 2, Recommendations 1 and 2). Current course requirements for admission to medical school (i.e., one year of physics, one year of biology, two years of chemistry for Rush Medical College) are increasingly seen as too restrictive and leading to too early specialization; one prominent medical school has recently dropped all entering course requirements (5).

At the other end of the continuum, we are asked to more fully and explicitly define the knowledge and skills that are required for graduate medical education and, presumably, required for the practice of medicine (Conclusion 1, Recommendation 2).

In the preclinical years, the recommendations are many, but they can be readily summarized: reduce passive learning of facts (Conclusion 1, Recommendation 1; Conclusion 3, Recommendations 2 and 3) and increase active, self-directed learning and the development of problem-solving skills (Conclusion 3, Recommendations 2, 4, and 5).

**A RESEARCH AGENDA FOR PHYSIOLOGY**

How do we implement the many GPEP recommendations that are relevant to physiology? While the call to action is urgent and appropriate, our ability to respond effectively is limited by our ignorance about how students learn physiology and how faculty can best assist that learning process.

Here, then, is a preliminary agenda for research on the teaching of physiology. It is made up of a list of related questions that will need to be answered if we are to be able to implement the recommendations of the GPEP report. Each question can only suggest, in the broadest terms, research projects to be pursued; a detailed description of such projects will have to await the actual launching of this research. Although the issues raised here interact with one another to a significant degree, they can, nevertheless, be pursued independently of one another. While the immediate focus is on physiology teaching in a medical school curriculum, the questions to be raised apply to physiology teaching at any educational level. It is also likely that similar questions can be raised about each of the basic science disciplines that make up the preclinical medical curriculum.

If we begin at the beginning, we must inquire about the appropriate prerequisite for admission into medical school.

**What does one need to know to learn physiology?** What knowledge base in physics, chemistry, biology, and mathematics is required? What reasoning skills are required for mastery of physiology? What knowledge base and what process skills do medical students actually possess when they matriculate?

Implementing any recommendation to broaden the undergraduate education of medical school applicants is likely to result in reduced student preparation in the physical and biological sciences. However, without an analysis of cognitive demands of physiology it is not possible to know what an entering medical student ought to know to be successful. In this regard, it is interesting but hardly surprising that an analysis of student performance in physiology found that the single best predictor of a student’s cumulative score was his or her score on the physics portion of the Medical College Admission Test (MCAT) (Michael, unpublished observations, 1977). However, we do not know whether this means that biology and chemistry preparation is unimportant (or less important) and it does not define precisely what undergraduate physics is most useful for students of physiology. Arons (1) has identified what he regards as the basic assumptions that are made about student reasoning abilities at the undergraduate level, but these thinking processes are not assessed by the MCAT exam and there is little information to tell us whether entering medical students are, in fact, able to carry them out. We need to know what the prerequisites for physiology are and, as we will see below, we need to know what physiology is prerequisite for learning medicine.

Once we have admitted our class, a new set of questions arise.

**How should we teach physiology to most effectively assist students to attain the level of mastery we ask for?** How
should we teach the problem-solving skills we think are important? How should we evaluate the student's mastery of the knowledge and problem-solving skill that we expect?

There are many items on our teaching menu: lectures, laboratories, tutorials, etc. What combination of these represents the most effective educational program to facilitate acquisition of the desired facts and to structure the student's knowledge base in the most useful way (9)? In discussing the complex mechanisms that characterize human physiology, how do we simplify without oversimplifying and leading to incorrect application of this knowledge (8)? What are the most appropriate educational experiences to foster the acquisition of problem-solving skills? Exposure to selected examples of problems to be solved can be an important aspect of teaching problem solving (9), but we do not know what examples to use. It is well known that exams "drive" the curriculum (21). With this in mind, it is imperative that we devise objective evaluation instruments that assess both content and process skills and at the same time encourage students to learn in an appropriate manner.

Finally, important questions arise from the obvious fact that the physiology we teach first-year students is presumably in some sense prerequisite for later educational experiences in medical school.

What physiology content should we teach, and what problem-solving skills should we focus on to prepare our students to learn the other disciplines they will encounter during their progress through medical school? What physiology does a physician need to know and how is this knowledge to be used in his or her practice of medicine?

There is now evidence that appropriately sequencing courses (and their content) can significantly improve retention of material that is learned (2). However, we have only a rudimentary idea of what physiology needs to be mastered by first-year students to facilitate their learning of pathophysiology in the second year, or of medicine, surgery, etc., in their third and fourth years. In part, this reflects our continued uncertainty about the content of the knowledge base required by physicians, and we are equally ignorant about what problem-solving processes are used to carry out their diagnostic function. However, it must be remembered that even if physicians do not appear to use basic knowledge in arriving at a diagnosis (23), or do not use a particular problem-solving process in generating the diagnosis (22), there may be a need for certain basic science knowledge or certain problem-solving skills while they are learning to be physicians (11).

HOW REALISTIC IS THIS AGENDA: PHYSICS EDUCATION AS A MODEL

What are the prospects for obtaining answers to even some of the issues on my agenda? An examination of the situation in physics teaching suggests that it is certainly not impossible. Physics is a discipline that is cognitively similar to physiology in that both require that qualitative and quantitative problem-solving skills be applied to physical phenomena (force, heat, electrical potential, etc.). Although there is a significant difference in size (numbers of students and teachers) between the teaching enterprises of the two subjects, it is worth briefly looking at the situation in physics as a point of departure before assessing what can happen in physiology.

Even a brief survey of the cognitive science literature on problem-solving expertise reveals that physics is one of the most studied domains, in part because many cognitive scientists have had physics backgrounds and in part because physics problems are readily defined and their solutions are easily identified. At the same time, however, teachers of physics are actively engaged in examining all aspects of their endeavor, in many cases drawing directly on the cognitive science base that is being built.

It is clearly relevant that this activity is well supported organizationally by the American Association of Physics Teachers and that the journals published by this group (The Physics Teacher and the American Journal of Physics) are forums for both physics teachers and cognitive scientists.

On the other hand, in physics (12), as in physiology (17), the individual teacher/investigator does not always find the departmental or institutional support that is necessary if research efforts in this area are to flourish.

In physiology, it appears that the significance of teaching is gaining increasing recognition. The American Physiological Society has recently formed a Section on the Teaching of Physiology, which has become active in programming at the Society's Fall meetings and the FASEB meetings, and with the creation of this journal, Advances in Physiology Education, the Society will provide the community of interested physiologists a long-needed forum for discussion of ideas in this realm. Teaching, a concern common to all physiologists, whether of the "systems" school or the new "molecular biology" school, may increasingly become a rallying point for the discipline.

In summary, perhaps the prospects for the agenda that has been defined here can best be summarized by these words of Frederick Reif (27), a physicist, cognitive scientist, and educator, who is at the forefront in the attempt to advance the state of physics teaching. He has summed up the current state of things in this way: "There has been progress: Important educational issues have been identified; deleterious teaching practices have been uncovered; complex cognitive processes have become better understood; promising new teaching methods have been explored." Perhaps physiology—its teachers, educational researchers, and administrators—is now ready to attempt such progress.

APPENDIX: RECOMMENDATIONS FROM GPEP REPORT (3)

GERMANE TO PHYSIOLOGY TEACHING

Conclusion 1: Purposes of a General Professional Education

Recommendation 1. . . . medical faculties must limit the amount of factual information that students are expected to memorize.

Recommendation 2. The level of knowledge and skills that students must attain to enter graduate medical education must be described more clearly.
Conclusion 2: Baccalaureate Education  

Recommendation 1. Colleges and university faculty should require every student, regardless of major subject or career objective, to achieve a baccalaureate education that encompasses broad study in the natural and the social sciences and in the humanities.

Recommendation 2. In framing criteria for admission to medical school, faculties should require only essential courses. Whenever possible, these should be part of the core courses that all college students must take.

Conclusion 3: Acquiring Learning Skills  

Recommendation 2. Medical faculties should encourage students to learn independently by setting attainable educational objectives and by providing students with sufficient unscheduled time for the pursuit of those objectives.

Recommendation 3. Medical faculties should examine critically the number of lecture hours they now schedule and consider major reductions in this passive form of learning.

Recommendation 4. Medical faculties should offer educational experiences that require students to be active, independent learners and problem solvers, rather than passive recipients of information.

Recommendation 5. ...the evaluation of students' academic performance should be based in large measure on faculty members' subjective judgments of students' analytical skills rather than their ability to recall memorized information.

REFERENCES


