The Physiology undergraduate major in the University of Arizona College of Medicine: past, present, and future

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Submitted 5 August 2010; accepted in final form 10 January 2011

Henriksen EJ, Atwater AE, Delamere NA, Dantzler WH. The Physiology undergraduate major in the University of Arizona College of Medicine: past, present, and future. Adv Physiol Educ 35: 103–109, 2011; doi:10.1152/advan.00089.2010.—The American Physiological Society (APS) and APS Council encourage the teaching of physiology at the undergraduate, graduate, and medical school levels to support the continued prominence of this area of science. One area identified by the APS Council that is of particular importance for the development of future physiologists (the “physiology pipeline”) is the teaching of physiology and physiology-related topics at the undergraduate level. In this article, we describe the historical development and implementation of an undergraduate program offered through the Department of Physiology, a basic science department in the College of Medicine at the University of Arizona, culminating in a Bachelor of Science in Health Sciences degree with a major in Physiology. Moreover, we discuss the current Physiology curriculum offered at our institution and explain how this program prepares our students for successful entry into a variety of postbaccalaureate professional programs, including medical school and numerous other programs in health professions, and in graduate study in the Masters and Doctoral programs in biomedical sciences. Finally, we will discuss the considerable challenges that we have faced, and continue to face, in developing and sustaining a successful physiology undergraduate major in a college of medicine.

Development of the Physiology Major From 1991 to 2010

The Department of Physiology in the University of Arizona College of Medicine offers an undergraduate major in Physiology that emphasizes a systems level and integrative approach to studying biological functions of the human body, with a focus on biochemical, metabolic, endocrine, neurophysiological, and cardiorespiratory interactions. Upon completion of the program, the Bachelor of Science in Health Sciences (BSHS) degree, with a major in Physiology, is awarded. The major has experienced substantial transformations since its inception in 1990, and the evolution of the program is summarized below.

1991–1997. The undergraduate major program in Physiology was originally created as an “Exercise Sciences” major in the Department of Exercise and Sport Sciences located in the School of Health Professions. This new major was approved by the Arizona Board of Regents in October of 1990, and the first student to complete the program graduated in December of 1991. Several transitions and reorganizations have occurred since that time, resulting in changes in the name of this major, the curriculum required in the major, and the administrative home of the major. In 1995, due to a university-wide reorganization precipitated by the financial crisis of the early 1990s, the central administration made the decision to disestablish the Department of Exercise and Sport Sciences. The Physical Education Program in the Department of Exercise and Sport Sciences was originally slated to be eliminated but was instead moved into the College of Education. The academic program and the five tenure-track faculty members associated with the Exercise Sciences major were transferred to the Department of Physiology in the University of Arizona College of Medicine, although the major was still administered through...
the School of Health Professions. The considerable efforts of Dr. William H. Dantzler, Head of the Department of Physiology at the time and a former president of APS, were instrumental in facilitating this merger. For the next 2 yr, the Exercise Sciences major was offered through the Department of Physiology.

1997–2010. In 1997, the curriculum of the major was restructured to more broadly encompass coverage of all of the major physiological systems and to deemphasize exercise as a core component of the program, and the major was renamed the Physiological Sciences major. At this time, the faculty members from the original Department of Physiology began to take on an increasing role in teaching the restructured major, in addition to their significant teaching contributions in the medical school and in graduate programs. In 2005, another round of university reorganization brought the disestablishment of the School of Health Professions. Consequently, formal administration of the program was placed in the Department of Physiology, and the major took on its current name of Physiology. From 1991 until her retirement in 2006, the program in its various forms was directed by Dr. Anne E. Atwater. In 2006, Dr. Erik J. Henriksen became Director of the Physiology major, with substantial overall oversight provided by the Head of the Department of Physiology, Dr. Nicholas A. Delamere.

Currently, the Physiology major is the only undergraduate program in the College of Medicine, and it has experienced tremendous growth. The popularity of the Physiology major among undergraduate students is remarkable. Since 2002, the Pre-Physiology major has consistently ranked among the top five majors declared by new freshmen entering the University of Arizona, and from 2006 to 2009 ranked second among majors declared by the incoming class of undergraduates (Fig. 1).

The total number of Physiology premajors and major students has increased from 467 students in 2000 to ~1,500 students during the most recent academic year (Fig. 2). Approximately 60–70% of premajors declare the Physiology major, whereas the remainder either do not meet the major prerequisites (Fig. 3), change to a different major, transfer to another university, or drop out of the university entirely. In addition, numerous students transfer into the Physiology major from other programs at the university. Importantly, >90% of students that are admitted to the Physiology major graduate with a degree from the program. Since December of 2007, the program has awarded 723 BSHS degrees with a major in Physiology, reflecting an annual graduation rate of ~200–250 students per academic year.

The success of the Physiology undergraduate major can be measured not only in the number of students attracted to and graduating from this program but also by the accolades bestowed on the program by the University of Arizona administration. In May of 2006, the program received the “Provost’s Award for Meritorious Departmental Achievement in Undergraduate Instruction,” the highest award that can be given to an undergraduate degree program at the University of Arizona. This award, accompanied by $75,000 over a 3-yr period to support the teaching of our major, recognized the Department of Physiology’s outstanding accomplishments in teaching and the dedication of the faculty and staff to promoting academic rigor and research-based study in the area of physiology at the undergraduate level.

Undergraduate major programs in physiology within the United States are few in number, and, at present, there is no accrediting body that prescribes the curriculum for undergraduate physiology programs. A database organized by APS lists institutions in the United States offering physiology undergraduate studies (http://www.the-aps.org/education/Degrees/search.asp). Currently, 25 American universities/colleges offer a Physiology degree (BA/BS) and 13 American universities/colleges offer a Physiology major (BA/BS)—the latter group includes the University of Arizona. To our knowledge, the University of Arizona is the only United States university to offer a Physiology undergraduate major within a college of medicine.

Among the better-known undergraduate programs that have been in existence longer than the program at the University of Arizona are those at the University of California (Los Angeles, CA; Integrative Biology and Physiology in the College of Letters and Science) and Michigan State University (Physiology, administered jointly by the Colleges of Natural Science, Human Medicine, Osteopathic Medicine, and Veterinary Medicine). A newer program that has evolved from an exercise science origin is the Integrative Physiology undergraduate major at the University of Colorado (Boulder, CO; located in the College of Arts and Sciences). This program is also very large, numbering >1,300 students. To our knowledge, national rankings of Physiology undergraduate programs do not exist.

Fig. 1. List of the top five majors declared by incoming freshmen at the University of Arizona (UA) from 2006 to 2009.

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Fig. 2. Total number of Physiology majors and premajors at UA from 1991 to 2009 assessed on the 21st day (“census day”) of the fall semester.
Current curriculum in the major. Students can declare a Pre-Physiology major upon enrollment at the University of Arizona. The current curriculum in the Physiology major is shown in Fig. 3. In addition to the university-wide requirements in English, foreign language proficiency, and other general education courses in traditions and cultures, individuals and society, arts, and humanities, students in Physiology must complete several science and mathematics courses. These courses include two semesters of general chemistry, two semesters of organic chemistry, mathematics through calculus II, a year of physics, and a year of introductory biology. Pre-Physiology students, generally in their sophomore year, must complete the two-semester sequence of Human Anatomy and Physiology (PSIO 201 and PSIO 202), consisting of both a lecture and laboratory component. A detailed listing of topics covered both in the lecture and laboratory sections of these two courses can be accessed within the Physiology major website (http://www.physiology.arizona.edu/sites/default/files/PSIO%20201_202%20Table_0.pdf). This sequence is considered a gateway course in the major, and students must earn a minimum grade of “C” in both PSIO 201 and PSIO 202 to continue in our degree program and take upper-division core and elective courses.

Upon successful completion of PSIO 201 and PSIO 202, and having passed courses in English composition, first-semester calculus, and general chemistry, Pre-Physiology students may apply for admission to the Physiology major. Admission to the major requires a minimum cumulative grade point average (GPA) of 2.250 and a GPA in physiology courses of 2.000. The University of Arizona, a public land grant institution, does not currently encourage measures to “cap” enrollment in the Physiology major or in other heavily enrolled undergraduate majors.

The Physiology major curriculum consists of 30 units (semester credit hours) and is subdivided into required courses (18 units) and elective courses (12 units) (Fig. 3). The required, or core, courses are Human Anatomy and Physiology (PSIO 201 and PSIO 202), two semesters of an Integrative Cellular Physiology course (PSIO 303a, PSIO 304, and PSIO 303b; see below), and one semester of general protein and metabolic biochemistry (a service course for non-Biochemistry majors offered through the Department of Chemistry and Biochemistry). The remaining 12 units must be fulfilled by completion of 3 courses from a menu of upper-division electives in cardiovascular physiology, endocrine physiology, neurophysiology, human reproductive physiology, respiratory physiology, immune physiology, cardiac and skeletal muscle biology, exercise and environmental physiology, assessment of body com-
position, inflammation and disease, neuroendocrine control of systems physiology, mathematical modeling of physiological systems, scientific methods and professional ethics, and scientific issues in society. Physiology majors are permitted to select one course from an approved list of physiology-related courses offered outside of the Department of Physiology that can substitute for one of these upper-division electives.

Students in the Physiology major also have the opportunity to enroll in up to six units of independent study courses. Throughout the curriculum there is a strong emphasis on research discoveries that have contributed to the current base of knowledge in physiology. Moreover, many of the larger courses in the curriculum are taught by senior faculty members who are leaders in their respective research fields and have active research programs. Consequently, many Physiology students develop a keen interest in physiology-related research, and, each semester, ∼90 students choose to do independent study projects, involving cutting-edge research in laboratories in the Department of Physiology and across the entire University of Arizona campus. Many of the Physiology students are accepted into the University of Arizona Honors College (currently 305 students) and will graduate with honors. To meet the needs of this select group, Dr. Lucinda Rankin in the Department of Physiology has organized and directs the Physiology Honors Academy. The Physiology Honors Academy serves as a home for these Honors students during their time at the University of Arizona, and Dr. Rankin provides formal (PSIO 295H: Introduction to Honors) and informal guidance in how to best complete the honors thesis requirements. Requirements for the honors thesis are set by the thesis advisor but typically include the completion of a research project in the laboratory and a formal report on that project, such as a scientific article, poster presentation, or oral presentation.

Recent curriculum changes in the Physiology major. Until 2009, required course offerings in the Physiology major included Introduction to Cell Physiology, a one-semester four-unit survey course on basic aspects of cellular function, and Human Physiology, a one-semester upper-division survey course coconvened with pharmacy doctoral students and covering basic physiological systems. Student feedback indicated that these core courses were in need of attention. Many students expressed the desire for courses that had a greater focus on physiological function in health and on dysfunctions at the molecular, cellular, and systems levels associated with disease states and provided more integration of cell physiology with systems physiology. After much debate among Department of Physiology faculty, in late 2007, it was decided that the Introduction to Cell Physiology and Human Physiology courses were not optimal for meeting the needs of our Physiology undergraduates and they should be replaced with several new courses starting in the fall of 2009. Replacing these two courses was not an easy decision, particularly because of the radically different approach required to teach the basic principles of physiology in the new courses to large numbers of students.

One new course is a two-semester sequence of Integrative Cellular Physiology (PSIO 303a, PSIO 304, and PSIO 303b, 7 units total) that presents basic physiological concepts, organized in “blocks” (signal transduction, membrane transport, cell-cell and cell-tissue communication, function of subcellular structures, regulation of gene transcription and cellular development, and regulation of cardiac contractility). Each block is presented in the context of a relevant physiological or pathophysiological scenario and, in many respects, is similar to the “case study” teaching approach we use in the medical school curriculum. For example, signal transduction is presented using the regulation and dysregulation of whole body glucose homeostasis as the case study. The instructor follows the progression of an imaginary group of individuals whose glucose regulation is deteriorating and presents the metabolic and cardiovascular consequences. The signaling elicited by neural and endocrine input to the skeletal muscle, liver, adipose tissue, and vasculature needed to maintain blood glucose concentrations within a fairly tight range and the etiology and consequences of defects in these signaling processes are covered in this section of the course. In this way, a case study on glucose dysregulation is used as the platform for teaching certain key concepts in cell and systems physiology. Relevant state-of-the-art research techniques and experimental approaches are also covered in accompanying discussion sections (PSIO 304, representing 1 unit of the 7 total units) led by graduate teaching assistants (GTAs). An overriding feature of this Integrative Cellular Physiology course is a teaching approach that provides required factual information on physiological processes at the cellular and molecular levels but ultimately integrates this information at the systems level in a meaningful way. Student feedback on this change has been broadly positive, and they appreciate the connection made between the molecular regulation of cell function and its impact on a relevant physiological process in the whole organism. Importantly, the students find Integration of Cellular Physiology interesting, and class attendance is far higher than it was in previous upper-division core survey courses in the major.

To fill the gap left by the discontinuation of the survey course Human Physiology (5 units), we introduced several new upper-division elective classes (3 units each) that focus on a particular area of physiology. The new offerings include Neuroendocrine Control of Systems Physiology, Respiratory Physiology, Reproductive Physiology, and Cardiac and Skeletal Muscle Biology. There are plans to introduce a new course on gastrointestinal and renal physiology in the near future. Each new elective course, as is the case with the upper-division electives offered already, is taught by accomplished experts in the respective field. This allows the presentation of material at a much deeper level of coverage and with more reference to research than was previously possible in the Human Physiology survey course.

Professional Preparation of Physiology Majors

What are the goals and aspirations of Physiology majors at the University of Arizona? In April of 2010, a survey of all Physiology majors and premajors provided the following information (Fig. 4): >50% of the Physiology students want to go to an allopathic medical school, ∼10% wish to enter a postbaccalaureate program in physical therapy or occupational therapy, 7% want to become physician assistants, 5% wish to gain acceptance to graduate school in a biological science (Masters or Doctoral programs), 3–5% want to pursue dentistry, the field of sports medicine, nursing, or a doctorate in pharmacy, and the remainder expressed an interest in various
other professions (doctor of osteopathic medicine, chiropractic, optometry, pharmaceutical sales, podiatry, secondary school teacher, and military).

An important component of the APS 2006–2010 Strategic Plan (http://www.the-aps.org/about/2006StrategicPlan.pdf) is the implementation of mechanisms to increase the presence of physiology in undergraduate education (Direction 2, Strategy 2 of the plan). The Physiology major at the University of Arizona fulfills all of the needs encompassed by this directive. The major provides a comprehensive set of physiology courses that serve to educate students in all of the primary areas of physiological investigation, and many of our physiology courses are taken by nonphysiology students, as space allows. Students graduating with a major in Physiology are well positioned to gain acceptance to most programs providing postbaccalaureate training in health careers. Moreover, students in the Physiology major have numerous opportunities to engage in meaningful undergraduate research experiences. These particular students are very competitive applicants to graduate programs offering Masters and Doctoral degrees in physiology and related areas. Each year, several of our undergraduate majors present posters at the Experimental Biology meeting.

The Physiology major addresses a further directive of the APS Strategic Plan, which tasked undergraduate faculty to be partners in developing the physiology pipeline. The ultimate goal of this physiology pipeline is to encourage undergraduate students to pursue a career as a basic research scientist in a physiology-related field. Dr. Henriksen, Director of the Physiology major at the University of Arizona, and Dr. Roger Enoka, Director of the Integrative Physiology major at the University of Colorado, were asked in 2009 to serve on the APS Physiology Pipeline Taskforce and have provided valuable perspectives on potential benefits that emerge from large and successful undergraduate majors in physiology and how the programs have evolved to become vital parts of this physiology pipeline. By sharing their experiences, these individuals will help guide discussion on the presence of physiology in undergraduate institutions and ways that the curriculum and teaching methods can be optimized over the coming years.

The Exercise Sciences major was created in 1991 in response to clear student interest in, and request for, more substantive coursework in exercise physiology and related sciences. However, it was not until the exercise sciences faculty and the major program were transferred to the Department of Physiology in 1995 that curricular changes were designed and implemented over the following 2 yr to reflect the primary emphasis on physiology. The restructuring of the curriculum was accomplished by months of committee work, faculty discussion and debate, and a welcomed collegiality from Department of Physiology faculty members whose prior teaching responsibilities had been solely in graduate and medical school courses. With the addition of 5 Exercise Sciences faculty members to the 14 Physiology faculty members, the Department of Physiology took on greatly expanded teaching responsibilities.

Teaching at all levels represents a major time commitment for the 18 tenure-track and tenured faculty members and 7 lecturers currently in the Department of Physiology. Teaching loads are determined by the Department Head in conjunction with recommendations of the departmental Curriculum Committee. The teaching loads of the 12 tenure-track and tenured faculty members who cover courses in the Physiology major can vary quite a bit from individual to individual but, on average, consist of teaching significant portions (30–50%) of two courses each year. The department faculty members also teach physiology in a significant portion of the medical school curriculum and the core courses (cell physiology and systems physiology) in the graduate (Masters and Doctoral) Physiological Sciences Graduate Interdisciplinary Program (PSGIDP). Teaching responsibilities in the restructured medical school curriculum represent a central and primary commitment expected of Department of Physiology faculty members, particularly from the perspective of the College of Medicine administration. In addition, the faculty are actively involved in conducting research as well as mentoring graduate and undergraduate students in their research projects. Needless to say, the expansion of the Physiology undergraduate program since 2001, as shown in Fig. 2, has put a considerable strain on Department of Physiology faculty. The faculty members now teach more courses, and, critically, the size of undergraduate physiology classes has increased tremendously, with enrollment in some lecture courses (e.g., PSIO 201) exceeding 500 students. The core courses in Integrative Cellular Physiology (PSIO 303a/304 and PSIO 303b) serve upwards of 325 students each semester, and popular upper-division elective courses can each enroll ~100–150 students. Teaching these undergraduate courses would not be possible without the considerable efforts of the lecturers in our department, who teach, on average, the equivalent of two courses each semester and, in some cases, also serve as course coordinators. Inevitably, large classes come at the expense of personal interactions between teaching faculty members and students.

The location of the Physiology major in the College of Medicine is attractive to some students who view it as a step closer to medical school. Administratively, however, the College of Medicine is outside of the mainstream of the university’s undergraduate operations. As a result, the Physiology major
Historical Perspectives

has experienced rather low “program visibility” at the college and university levels, with many ramifications in the past and present. In contrast, students seem to have had little difficulty in locating and joining the major program, despite its changes in location over the years (from the Department of Exercise and Sport Sciences, to the School of Health Professions, and then to the Department of Physiology in the College of Medicine). The ever-increasing enrollments in the major attest to this fact. As a biological science major lying outside the usual domain for such undergraduate programs, which are typically found in the College of Science on the main campus, the Physiology undergraduate major has often been difficult to understand for some college and university administrators. The educational focus within the College of Medicine is primarily on medical students, not undergraduates. Understandably, the university administration has tended to focus attention and resources on the “traditional” colleges on main campus, and the College of Medicine is viewed as a distinctly separate college educating medical students. As a result, recognition of the resources needed to manage the Physiology undergraduate program’s escalating enrollments, large class sizes, and heavy faculty teaching loads has been low on the priority list at both college and university administrative levels.

In 2006, the large increases in enrollment in the Physiology major came to the attention of the Vice President for Instruction, at a time when it was typical for upwards of 200 students to be denied enrollment in PSIO 201 and PSIO 202, Human Anatomy and Physiology, due to a lack of available seats. Funds were provided to hire one tenure-track faculty member, one full-time lecturer, and one full-time academic advisor in 2007. In 2008, the number of seats offered in PSIO 201 and PSIO 202 was increased substantially by offering each course in both the fall and spring semesters. Despite this expansion, demand for PSIO 201 continues to outstrip seat availability. There was to be a second phase of the expansion, with additional resources provided to hire new faculty members to help teach additional upper-division electives. Unfortunately, the second phase was scuttled by the economic crisis that began in 2008. In 2008 and 2009, the Department of Physiology experienced cuts that amounted to an 11% reduction in the permanent budget. The result was a “perfect storm,” with the Physiology major experiencing a large increase in enrollment and a simultaneous decline in resources. Using data from the 2007–2008 academic year, university administrators recently compared undergraduate student credit hours to the budget dollars for support of this undergraduate teaching. The Department of Physiology figure of $102/student credit hour is one of the smallest at the entire university.

Human Anatomy and Physiology (PSIO 201 and PSIO 202) is a required course for Physiology majors and several other majors at the University of Arizona. This two-semester sequence constitutes at least half of the total student credit hours taught by the Department of Physiology. These two courses enroll between 800 and 850 students/semester and serve not only Physiology premajors students (~40–45% of the total enrollment) but also Pre-Nursing students (10–15%), Pre-Pharmacy students (10–15%), and students from several other major programs. In both courses, the majority of the lectures are given by full professors in the Department of Physiology, who have active research programs and, in 2009–2010, procured approximately $1,800,000 in annual extramural research support. The 30 laboratory sections associated with PSIO 201 and PSIO 202 each semester are taught by GTAs. The GTAs come primarily from the PSGIDP. By providing teaching assistantships, the Physiology program is a major source of support for the PSGIDP. The recent expansion of PSIO 201 and PSIO 202 has opened new GTA slots, permitting a significant increase in graduate student admissions for training in physiology. The need to recruit a dozen or more reliable and competent GTAs introduces its own set of issues. From a teaching perspective, excellent communication skills of the applicant are prized, as is evidence of prior teaching activity and previous experience in studying human anatomy and physiology. Naturally, the graduate student admissions committee may have other priorities, and this faculty group is faced with a tough decision-making process where the outcome requires considerable patience and cooperation.

Perspectives

Despite the current mismatch between high student enrollments in the Physiology undergraduate major and the resources available to optimally support this program, there is considerable agreement among students, faculty, and parents that the program is very successful. The rigorous curriculum attracts high-caliber students, many of whom have achieved their goal of entering postgraduate studies in healthcare fields or in academic disciplines. Does it benefit the Department of Physiology to offer an undergraduate major in Physiology? Almost certainly, the answer is a resounding “yes.” The success of the undergraduate major has given the Department of Physiology the unique ability to teach at all levels within the university, offering a curriculum that is becoming increasingly seamless. The PSGIDP is strengthened by teaching assistantships coupled to our undergraduate courses as well as by the natural presence of more and more excellent Physiology majors wanting to stay on to earn Masters or Doctoral degrees.

Across the university, awareness of physiology as a scientific discipline is on the upswing as more and more students pass through the Physiology major. An increasing percentage of incoming undergraduates seem genuinely interested in systems physiology as a way of thinking about how the body works. In many ways, this is deeply satisfying to the Department of Physiology faculty. Who doesn’t like sharing their story with eager learners? Who doesn’t want to teach the next generation of physiologists? Is it to their great credit that the Physiology faculty stepped forward and embraced the major. The Physiology undergraduate program could not have achieved its present level of success without the decade-long dedicated efforts of the Department of Physiology faculty in significantly stretching their teaching and research-mentoring involvement to include undergraduate students. In addition, it needs to be emphasized that successful implementation of the Physiology major has required departmental and university support for a program coordinator, an administrative secretary, and three full-time academic advisors.

It is hoped that the information provided in this article on the Physiology major offered by the Department of Physiology in the College of Medicine at the University of Arizona will encourage individuals at other universities and colleges who may be contemplating the development and implementation of an undergraduate program in Physiology. It is clear that the
primary challenges for delivering a similar curriculum in physiology at the university level are having a critical mass of enthusiastic teaching faculty in a department, having the necessary infrastructure of classrooms and laboratory space, and having the financial resources available on a permanent basis to fund faculty, staff, and teaching laboratories. The Physiology major at the University of Arizona stands as an example of a program that, through the concerted efforts of dozens of individuals, both past and present, has met these challenges and is fully engaged in training the next generation of physiologists.

DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the author(s).