

Volume: 78
Issue No. 3
Year: 2026



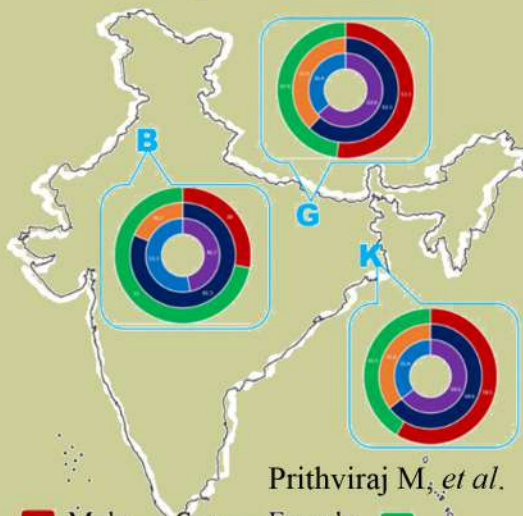
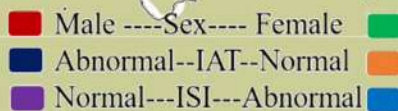
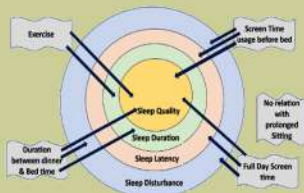
Indian Journal of Physiology and Allied Sciences

An official peer-reviewed journal of

The Physiological Society of India

IJPAS

Vol. 78; No. 3; Year 2026

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Physiology: The Nucleus of Medicine and Biomedical Sciences

Susan M. Barman^{1*}, Erica A. Wehrwein²

ABSTRACT

Physiology underpins biomedical science and clinical medicine by integrating molecular mechanisms into overall body functions. Tracing back to pioneers like William Harvey and Claude Bernard, its significance is highlighted by landmark discoveries and Nobel Prizes awarded for fundamental physiological insights. Although it effectively links basic sciences such as anatomy and pharmacology to pathophysiology, modern physiology education in the 21st century faces significant obstacles. Major issues include crowded curricula, shifts to integrated learning models, limited dedicated study time, and a lack of widely trained educators.

In response, global initiatives have emerged to revitalize physiology pedagogy. Programs like the Inter Medical School Physiology Quiz (IMSPQ) promote student engagement, while organizations such as the Physiology Majors Interest Group (P-MIG), the APS Center for Physiology Education (CPE), and the Human Anatomy and Physiology Society (HAPS) offer benchmarked learning outcomes and faculty development. Regionally, workshops by the Indian Council of Medical Research (ICMR) have introduced active learning strategies, and African initiatives have established competency-based guidelines and international mentorship networks. Collectively, these initiatives foster collaboration, refine curricular frameworks, and sustain the vital trajectory of physiology as the science upon which medicine and life depend.

Keywords: Physiology Education, Active Learning, Curriculum Integration, ICMR, Medical Education, Homeostasis, Pedagogical Training
Indian Journal of Physiology and Allied Sciences (2026); DOI: 10.55184/ijpas.v78i03.650 ISSN: 0367-8350 (Print)

INTRODUCTION

British physiologist Ernest Starling (1866–1927) highlighted the critical interrelationship of physiology and medicine when he said: *“The physiology of today is the medicine of tomorrow.”* The importance of physiology in medical education was also highlighted by Abraham Flexner in his landmark 1910 report on medical education: *“Physiology is, in a sense, the central discipline of the medical school.”* Indeed, we can only understand what goes wrong in disease (pathophysiology) and develop a rational scientific basis for the treatment of that disease (pharmacology and medicine) if we first know how living organisms function normally (physiology).

This message is echoed in a recent national campaign of the American Physiological Society (APS) entitled FIGHT FOR PHYSIOLOGY, designed to raise awareness for physiological research, defined as the science driving human health. This campaign aims to protect scientific momentum, supporting areas like cardiovascular health, metabolism, and specialized research on topics like women’s health. Their motto is *“Physiology is the science life depends on.”*

Historical Perspective and the Nobel Prize

From a historical perspective, William Harvey (1578 - 1657) deserves credit for his physiological discovery that the heart acted as a pump, circulating blood through the body in contrast to a centuries-old belief that blood was produced in the liver and consumed by the body. In the 18th and 19th centuries, physiology became recognized as a distinct scientific discipline.¹ Claude Bernard (1813 - 1878) is credited as the father of experimental physiology as he established the importance of controlled laboratory experimentation,

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How to cite this article: Barman SM, Wehrwein EA. Physiology: The Nucleus of Medicine and Biomedical Sciences. *Indian J Physiol Allied Sci* 2026;78(3):6-9.

Conflict of interest: None

Submitted: 18/07/2026 **Accepted:** 05/08/2026 **Published:** 30/09/2026

pioneered the use of animal models to understand human physiology, and introduced the concept of maintenance of our internal milieu (homeostasis).

The Nobel Prize in Physiology or Medicine was the 3rd prize designated in Alfred Nobel’s will in 1895, increasing the stature of physiology as an important medical science. The award honors fundamental discoveries in biological mechanisms (physiology) and their practical applications in treating disease (medicine). A few examples of how physiology was highlighted by the efforts of the honorees since it was first introduced:²

- In 1904, Ivan Pavlov was recognized for his work on the physiology of digestion.
- In 1923, Frederick Banting and John Macleod were rewarded for the discovery of insulin, which changed diabetes from a fatal diagnosis into a manageable chronic condition.
- In 2021, David Julius and Ardem Patapoutian received recognition for their separate but complementary

discoveries of receptors for temperature and touch, explaining the physiological basis for converting physical forces into electrical nerve impulses to recognize pain and temperature.

Physiology Drives Other Biomedical Sciences

Physiology links molecular events to cellular responses, tissue behavior, organ function, and whole-body performance. A defining feature of physiology is its integrative nature. This makes it the bedrock of all biomedical sciences, including anatomy, biochemistry, epidemiology, genetics, immunology, microbiology, molecular biology, neuroscience, pathophysiology, and pharmacology. Indeed, physiology synthesizes diverse biomedical topics into functional narratives and clinical diagnosis.^{3,4}

- Anatomy describes the structure, and physiology explains how those structures function in a coordinated fashion. Structural damage impairs function; functional stress can damage structure.
- Biochemistry identifies molecules and reactions like glycolysis and hormone synthesis vital for cellular function; physiology explains how and when biochemical pathways activate in living organisms. For example, hormones like insulin and cortisol are characterized biochemically and explained physiologically for their whole-body physiological effects.
- Genes encode proteins like enzymes and ion channels that drive cellular and organ functions; physiology explains how genetic mutations affect cell behavior and lead to clinical symptoms. Integrating genetics and physiology enables better disease risk prediction and targeted treatments.
- Drugs act by binding to receptors, enzymes, transporters, and ion channels to influence physiological functions. Pharmacokinetics (absorption, distribution, metabolism, and excretion) depend on physiological factors like blood flow and organ function.
- Molecular biology explains mechanisms at the gene and protein level, but physiology explains how those mechanisms establish system-level function.

Challenges Facing Physiology Educators

Despite the critical importance of needing knowledge of physiology to understand disease and identify treatments, there are many challenges facing physiology educators across the globe in the 21st Century.⁵⁻⁷ Some examples are:

- Awareness of the need to use varied approaches to support student engagement, accessibility, and application of physiological concepts (visual vs auditory learners; lectures vs active learning)
- A move away from traditional physiology courses to blended multidisciplinary courses
- Not enough dedicated time to teach and learn integrative physiology
- Need for more benchmarking of curriculum (different learning outcomes, contents, and milestones)

- A lack of resource materials, trained workforce, and institutional support to implement active learning strategies.
- Need to prepare the next generation of physiology educators, including students and trainees who may become educators but have limited opportunities for formal development of teaching skills
- Need for greater recognition, support, mentorship, and professional development for faculty who contribute substantially to physiology education
- Concerns about the future workforce of broadly trained physiology educators and the need to create pathways that prepare and retain individuals capable of teaching integrative physiology across educational settings.

Physiology Educators Meet the Challenges

Luckily, physiology educators are resourceful individuals and have developed opportunities to improve physiology education, including:

- Initiate partnerships with relevant stakeholders on advocacy to attract more funding for physiology education
- Develop mentorship and training programs to enhance physiology education
- Implement the use of core concepts of physiology in the curriculum
- Align curricular content with accreditation standards
- Develop common assessment procedures to evaluate critical thinking, problem-solving, and applied knowledge
- Include professional skills training for faculty and students with particular attention to science communication

Some specific examples include:

In 2003, Prof. Cheng Hwee Ming organized the first Inter Medical School Physiology Quiz (IMSPQ), with just seven national medical schools competing for the Prof. A. Raman Challenge Trophy, established in honor of Malaysia's first Professor of Physiology. IMSPQ was founded to boost student interest in physiology through intellectual competition and integrative learning. The event fostered collaboration and mutual respect among students and faculty beyond the competition itself. Since its initiation, IMSPQ has inspired national physiology quizzes in multiple countries, amplifying its educational impact globally. IMSPQ shapes learning approaches, teaching, and clinical reasoning, fostering collaboration and inclusiveness.⁸

A national grassroots organization called Physiology Majors Interest Group (P-MIG) was founded in 2014 by John Halliwill (University of Oregon), Erik Henriksen (University of Arizona), Dan McCann (Gonzaga University), and Erica Wehrwein (Michigan State University). Although it was formed in the US, it has become a global community for undergraduate programs and program directors that promotes communication, collaboration, and the use of core concepts in physiology education. P-MIG has supported efforts to characterize undergraduate physiology programs,

develop program guidelines, and share approaches to curriculum, assessment, and student learning outcomes. These efforts illustrate how educators can work collectively to address common challenges and strengthen physiology education across institutions.⁹

Building on growing recognition of the need for coordinated support for physiology educators, P-MIG was a stepping stone to an even larger initiative under the direction of the APS called the Center for Physiology Education (CPE) to nurture and promote excellence in teaching and learning of physiology. CPE aims to cultivate a vibrant and inclusive community of physiology educators and foster a shared vision of physiology education. CPE provides exceptional curricular, pedagogical, and career development resources in hopes of raising the profile of physiology as a discipline within academic and funding agencies.¹⁰ Together, initiatives such as P-MIG and the APS CPE demonstrate the value of creating communities and shared resources to support educators who face common challenges across institutions and educational settings.

The Human Anatomy and Physiology Society (HAPS) provides another longstanding community supporting excellence in physiology education. HAPS brings together educators teaching anatomy and physiology across a wide range of institutions and provides professional development, educational resources, conferences, and opportunities for collaboration. An important recent contribution is the development of the HAPS Physiology Learning Outcomes¹¹ to provide a shared framework for what students should know and be able to do in undergraduate physiology courses. The outcomes integrate physiological content with core concepts and scientific process skills while also addressing contemporary considerations in terminology, eponyms, and inclusive language. This work provides educators with a resource for curricular design and alignment while allowing flexibility in how individual courses and programs achieve these outcomes. Such community-developed learning outcomes can help address the challenge of determining what content is essential in an increasingly crowded physiology curriculum while providing common points of reference across diverse courses and institutions.

In 2018 and 2019, the Indian Council of Medical Research (ICMR) Workshop Series on Physiology Education Techniques was held to introduce physiology educators to active learning strategies in medical physiology education (flipped-classroom, case-based learning, and problem-based learning), to facilitate exchange of knowledge about best practices in physiology teaching, and to improve the quality of physiology teaching through creating networks and working groups of trained teachers of physiology in basic sciences, medicine, animal sciences, and dentistry.¹²

To address shortcomings experienced in physiology education in Africa, in 2023 a competency-based curriculum development guideline was introduced during the joint East African Society of Physiological Sciences and African

Association of Physiological Sciences conference in Tanzania. It is a freely available resource with 23 modules to help universities in Africa draft a curriculum suitable for their local needs and to benchmark and revise current curricula.¹³

In 2024, the IUPS established a mentoring program for early career physiology educators in Africa. The goals of the program were to allow the mentees to learn new methods in physiology education, develop new skills and knowledge in the facilitation of learning of physiology, help with career advancement, and gain increased scholarly confidence. The APS generously provided each mentee with a 2-year APS membership, providing them with access to a plethora of resources available online.¹⁴

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PEER-REVIEWED CERTIFICATION

During the review of this manuscript, a double-blind peer-review policy has been followed. The author(s) of this manuscript received review comments from a minimum of two peer-reviewers. Author(s) submitted revised manuscript as per the comments of the assigned reviewers. On the basis of revision(s) done by the author(s) and compliance to the Reviewers' comments on the manuscript, Editor(s) has approved the revised manuscript for final publication.

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