Physiology in the age of transformation: From synapse to sustainability

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ABSTRACT

Physiology is evolving from a traditional science of life processes into a dynamic discipline at the intersection of biology, technology, and global responsibility. At the molecular level, the synapse symbolizes adaptability and intelligence, offering insights for artificial neural networks while reminding us that survival, not computation, defines authentic learning. As physiology education shifts from rote memorization to inquiry-driven understanding, its principles of balance and resilience extend to planetary health, fostering inquiry, reasoning, and clinical integration while underscoring its ethical role in sustainability. From synapse to sustainability, physiology now teaches not only how life works but also how it can flourish responsibly.

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Physiology at the Crossroads of Transformation

Physiology, once regarded as a narrowly defined study of life processes, is now poised at the cusp of a profound transformation. Traditional boundaries separating biological insight, technological advancement, and global responsibility are rapidly dissolving, ushering in a new integrative paradigm. Within this framework, the study of living systems must actively incorporate artificial intelligence (AI), self-directed learning, and sustainability. Physiology is no longer a static repository of knowledge confined to textbooks; rather, it is a dynamic, evolving discipline that continually adapts and equips us to understand and respond to change. Its scope now extends from the molecular to the planetary, from the individual learner to the collective future of humanity.

From Synapse to Silicon

At the molecular and cellular level, the synapse remains the most elegant metaphor for connectivity and learning. It embodies the dynamic balance between excitation and inhibition, input and output, signifying a natural architecture of intelligence. This biological design is not merely a mechanism of communication but a principle of adaptability, resilience, and creativity. Recent studies demonstrate this reciprocity: neuromorphic chips now mimic synaptic plasticity to optimize learning efficiency,[1] while physiologic data from wearable sensors train adaptive models that predict cardiovascular stress and metabolic states.[2] As AI reshapes modern science, the biological model of the synapse is reflected in artificial neural networks. Yet physiology reminds us that the essence of intelligence lies not in raw computation but in context, shaped by adaptability, feedback, and purpose. Machines may learn patterns, but biological systems learn to survive, to adapt, and to thrive in unpredictable environments. This distinction is critical: survival requires meaning, not just memory.

Physiologists, therefore, play a unique role in bridging the artificial and the organic. By elucidating how biological systems achieve balance and resilience, they can guide the ethical and purposeful application of AI. The challenge is not to replicate biology in silicon but to ensure that technology remains a tool for human advancement rather than a source of alienation. In this way, physiology serves as a translator between two worlds, reminding us that intelligence is not only about efficiency but also about wisdom, compassion, and survival.

From Memory to Meaning

Parallel to this digital transformation lies another frontier: the reimagining of education. For decades, physiology teaching emphasized mechanistic explanations of organ function, often in isolation. Students memorized pathways, equations, and definitions, but frequently struggled to connect these fragments into a coherent understanding of life. Today, physiology education is evolving toward integrative, learner-centered models. These approaches link molecular processes to systems behavior and clinical outcomes, weaving together the threads of biology into a coherent framework.

Empirical studies in medical and allied physiology courses reveal that problem-based and flipped-classroom models significantly improve conceptual retention and application.[3,4] The integration of generative AI tutors has further enabled personalized feedback and metacognitive reflection.[5]

These approaches align with global calls for outcome-based curricula and the United Nations Educational Cultural and Scientific Organization (UNESCO) framework on lifelong, self-directed learning.[6] However, as access to information becomes universal, the true educational challenge shifts from knowing to understanding, from recall to reasoning.

The physiology classroom should evolve into a space that nurtures curiosity, inquiry, and metacognition, where learners construct meaning rather than accumulate facts, ask why and how, and translate principles into practice. Teaching physiology today is not about creating data repositories but about cultivating thinkers who translate principles into practice. The shift from "memory to meaning" mirrors the broader transformation from passive learning to self-directed discovery. It reflects the recognition that education is not preparation for life but life itself, a continuous process of inquiry and growth. In this vision, physiology becomes not only a science but also a pedagogy of resilience and creativity.

From Survival to Sustainability

Finally, the sustainability crisis compels every scientific discipline to introspect. Physiology, which studies balance and homeostasis within the organism, therefore must extend its insights to the planetary scale. For instance, physiological research on heat tolerance and hydration dynamics informs public health responses to climate-related morbidity.[7] The emerging field of planetary physiology explores how human thermoregulation, metabolism, and endocrine adaptation intersect with planetary boundaries.[8,9]

As the climate warms, resources deplete, and health inequities widen, the physiologist's understanding of adaptation and resilience becomes ever more relevant. Environmental physiology examines how organisms survive in extreme conditions; planetary health underscores that human well-being is inseparable from ecological balance. Recently, educational initiatives have embedded sustainability modules into biomedical training to prepare scientists for eco-ethical decision-making.[10] The ethics of resource use in research underscores science's responsibility to minimize harm and maximize benefit.

Physiology thus holds a moral responsibility to translate biological balance into sustainable living. It can illuminate how systems adapt to stress, how resilience is built, and how equilibrium can be restored. By extending its principles beyond the organism to the biosphere, physiology becomes a discipline of stewardship guiding humanity toward practices that sustain life rather than exhaust it.

The Way Forward

Physiology traces a path from the synapse to sustainability, embodying the expansion of connection across scales of life. The International Union of Physiological Sciences (IUPS) report (2025) emphasizes a continuum from molecular innovation to planetary responsibility as central to the discipline's future, urging physiologists to engage in interdisciplinary collaboration across data science, education, and sustainability policy.[11] From neural circuits to learning networks, from individual resilience to global responsibility, its purpose extends beyond the description of biological function. It reveals not only how life works but how it may flourish.

In this transformative era, physiology must remain the science that teaches us to live with intelligence, compassion, and care for all life and embrace technology without losing humanity. The discipline's future lies in integration: connecting molecules to ecosystems, learners to communities, and science to society. In doing so, physiology becomes not just a science of life but a science for life, sketching a guide to flourishing in a world of change.

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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.