The Biophysicist

# Hooking Nonscientists on Biophysics

**Raghuveer Parthasarathy**[1,*]

[1] Department of Physics, University of Oregon, Eugene, OR, USA

## Introduction

As biophysicists, many of us are keen on conveying the beauty and importance of our field to diverse audiences, including those who are not, and do not intend to be, scientists. In this report, I describe experiences communicating biophysics to nonscientists: nonscience major undergraduate students at a large, public US university, high school students, and general readers. I highlight approaches that help capture the attention of wider audiences, especially drawing on examples that illuminate health and disease.

Readers of this report presumably appreciate the value of biophysics. The fusion of biology and physics illuminates the workings of the living world and informs the design of practical tools and treatments. Biophysics encompasses marvels as diverse as the spinning of flagellar motors, the timekeeping of circadian clocks, and the coordination of flocks of birds. Naturally, many of us wish to convey the beauty and power of biophysics to nonscientists, and we feel that such communication will benefit our audiences, both in the abstract sense of providing a deeper appreciation of the natural world and in the practical sense of comprehending contemporary biotechnologies. A key question, then, is how to engage nonscientists. Of course, *nonscientists* is a broad category, encompassing among others college students majoring in a nonscientific subject, adults not professionally connected to scientific or technical fields and secondary school students whose educational aims are still amorphous. There are important differences between all such groups, but there are similarities as well.

Here, I describe experiences with each of the groups listed, noting strategies to capture the attention of nontechnical audiences. I will focus especially on lessons learned from a course I developed for nonscience major undergraduates at the University of Oregon, The Physics of Life (1); a popular science book on biophysics that I wrote, published in 2022, *So Simple a Beginning: How Four Physical Principles Shape Our Living World* (2); and activities for high school students in a day camp that targets socioeconomically disadvantaged students, Student Academy to Inspire Learning (3). My perspective is admittedly United States centric; it would be fascinating to contrast education across countries.

There are common obstacles to teaching biophysics to broad audiences. One is a very limited awareness of the existence of the field. Most people, in my experience, do not know that there exist physicists (or others with backgrounds in physical sciences) who study

"*" corresponding author

**Received:** 30 August 2022
**Accepted:** 31 October 2022
**Published:** 28 December 2022

living systems or biologic materials or that the study of biologic systems from a physical perspective has a distinguished past and a vibrant present. At the end of courses or activities presenting biophysical topics, it is common to hear or read statements such as, "I was surprised to learn that physicists study _____." There are many reasons for this absence of recognition. In middle and high school education, physics and biology are almost always presented as disjointed subjects. Compounding this, exposure to physics in any form is low, with about 60% of US students taking no physics classes in high school (4), and biology is often taught without an emphasis on mathematic analysis, bypassing a natural bridge between biologic and physical training. The popular media landscape reinforces a distinction between physics and biology, exacerbated by treatments of physics itself being unrepresentative of the field. In the popular consciousness, *physics* connotes subjects such as subatomic structure and cosmology, not superconductivity or nonlinear optics, let alone bacterial swarming or DNA packaging. At the time of this writing, Amazon's top 20 bestsellers in the category of physics include, for example, *Fundamentals: Ten Keys to Reality* by Frank Wilczek (5), *Astrophysics for People in a Hurry* and *Starry Messenger: Cosmic Perspectives on Civilization* by Neil deGrasse Tyson (6, 7), *A Brief History of Time* by Stephen Hawking (8), and *Existential Physics: A Scientist's Guide to Life's Biggest Questions* by Sabine Hossenfelder (9). A few books intersect a wide range of scientific topics, such as *What If? Serious Scientific Answers to Absurd Hypothetical Questions* (10) and *What If? 2: Additional Serious Scientific Answers to Absurd Hypothetical Questions* by Randall Munroe (11) and *Thinking in Systems: A Primer* by Donella H. Meadows (12), but none could be called biophysical.

Unawareness of biophysics hinders recruitment. The previously mentioned The Physics of Life course, has attracted about 40 to 70 students at each offering since its launch in 2011 (mean 56 students and standard deviation 10), which is more than some courses that similarly satisfy the university's general education science requirement, but considerably fewer than, for example, introductory astronomy (typically over 200 students). For scale, there are roughly 20,000 undergraduates at the University of Oregon. It should not be assumed, in my experience, that simply creating a course is sufficient to ensure its occupancy. Undergraduate course enrollment is a complex subject, but I note that communication with undergraduate advising staff, describing courses and their appeal, is an effective form of advertising. The previously mentioned high school camp has benefited from partnership with the university's human physiology department. The camp is part of a broader program known as the Student Academy to Inspire Learning (3), titled Physics and Human Physiology, with activities from faculty and students in each department, spanning a wide range of topics. This was the result of historical accidents rather than deliberate design, but it has turned out to be a great success, drawing in students who might not have signed up for a physics camp and who have been highly positive in assessments of the experience (see the following).

A second broad-reaching challenge is a general fear of math. It is hard to appreciate until teaching a course for nonscience majors how deeply ingrained an aversion to math is in many people. The causes of this discomfort are beyond the scope of this report, but I briefly note the following suggestions for addressing it. For now, I simply state it as an obstacle.

A third challenge for communicating biophysics to nontechnical audiences that applies mainly to formal courses is a shortage of ready-made materials, especially textbooks. In contrast to introductory courses aimed at science, technology, engineering, and math majors or more common general education science courses, for which numerous textbooks exist, there are, to my knowledge, no biophysics textbooks designed for nonscience major undergraduates. This is a considerable gap to bridge. Because the field is so large and amorphous, any choice of topics is likely to be incomplete and may not intersect the interests of the instructor. However, a useful approach may be to mirror the framework and contents of an existing, more technical biophysics textbook, such as *Physical Biology of the Cell* (13) or *Biological Physics: Energy, Information, Life* (14), whose authors have already mapped a path through the field. Another would be to write assignments or exercises that augment articles, videos, and books intended for nontechnical audiences. Regarding articles, descriptions of contemporary advances can be found in periodicals, such as *The Economist*, and journals such as *Science* and *Nature* publish expository text and video companions to research articles, to name just a few sources. Popular science books about biophysics are regrettably rare, and (15) provides a short list. This deficiency spurred me to write such a book (2), which may serve as a resource for other scientist–educators. A few examples of materials from these types of sources and the integration into learning experiences for undergraduate nonscience majors and high school students are described in the following.

## Hooks

Given the unfamiliarity of biophysics, a key question when addressing nonscience majors, high schoolers, or the general public is, what *hooks* grab people? Perhaps the most effective tactic is to connect biophysics to specific aspects of disease and human health. To some degree, this is obvious, but its power took me years to appreciate. Many, if not all, biophysical topics can be tied to issues of health and disease. I'll give a few examples here. On 9 August 1963, just 39 h after he was born, was the death of Patrick Bouvier Kennedy, the son of the President of the United States. The cause was infant respiratory distress syndrome (IRDS), an inability to breathe, which plagued premature infants such as Patrick and caused about 25,000 deaths per year in the 1960s in the United States alone. The mortality rate plummeted to less than 900 per year by 2005. Neither the ailment nor its cure involved the complex stratagems of pathogens or the intricacies of biochemical pathways, but rather the physics of soap films. Expansion of the lungs for breathing involves a large increase in surface area, which the lungs' liquid coating resists. Hence, one secretes surfactants to lower the surface tension of the lungs. Such secretions, however, begin rather late in gestation, leading to severe problems for premature infants. The solution is simple but effective: delivery of soap (or more precisely, an animal-derived or synthetic lung surfactant) to infant lungs. In the context of teaching, IRDS introduces the concept of surface tension, the nature of surfaces and interfaces, and the ability of molecules to self-organize. I begin a segment of my The Physics of Life class, as well as a high school activity involving soap films, with this example (1, 2). In all these venues, IRDS is a compelling entry point. It is not only dramatic, but also many people know people who were born prematurely or were premature themselves.

Another example is kuru, a fatal neurodegenerative disorder that can be spread via cannibalism and Creutzfeldt–Jakob disease, the human version of mad cow disease; these are disorders of protein structures in which the aberrant, misfolded form of particular proteins causes further misfolding and aggregation, spreading from victim to victim (16–18). The disease, therefore, not only helps introduce the biophysics of proteins in terms of the endpoints of structure but also the dynamics of folding. Still more generally, protein folding serves as an archetype of the general principle of self-assembly.

A host of complex polygenic traits and diseases from height to the risk of cardiovascular disorders is now amenable to prediction thanks to stunning advances in DNA sequencing technologies. Sequencing single-nucleotide polymorphisms from a DNA sample suffices, for example, to predict one's height within an accuracy of about an inch (19) or to identify breast cancer risks several times greater than average (20). These sequencing techniques are made possible by the physical properties of DNA as a stiff, highly charged polymer that can lead to discussion of these properties and the consequences.

Additional examples abound. There are, of course, diseases caused by bacteria and viruses that are intensely studied by biophysicists, aspects of embryonic development mimicked by engineered organoids, and large-scale physiologic characteristics that arise from fluid and solid mechanical concerns. Health and disease are universal, visceral concerns.

Effective hooks other than disease also exist. References to new discoveries or cutting edge research are appealing, especially if the research was performed locally. It can, however, be challenging to make contemporary research comprehensible or to cut through the breathless embellishments of press releases.

Finally, note that many people, including me, are fascinated by nature, especially in the form of photogenic animals. Again, many biophysical principles can be introduced via aspects of organisms' structures or behaviors. For example, small insects can stand atop water, but you and I cannot, a consequence of the properties of surface tension, especially the scaling of force with size. Running on water, as basilisk lizards can do, adds further complexity and illustrates differences between dynamic and static stability. Large animals have disproportionately large leg bones, a consequence of biomechanics. I show in class live water striders and an elephant femur; both are memorable. Birds have small genomes (bird red blood cells, unlike mammals, contain a copy of genomic DNA, which must share the available space with oxygen-carrying hemoglobin) compared with most other animals, which has been suggested to be evolutionarily linked to the demands of powered flight (21, 22).

Note approaches that are often unsuccessful for engaging wider audiences. Of course, some presenters may possess the charisma to make anything work. From experience, however, it seems that there are tempting paths that most of us should avoid. One is an appeal to elegance. Physicists are often drawn to phenomena for which a succinct, mathematically concise explanation applies. There are universal scaling exponents at phase transitions, for example, and Poisson distributions arise in contexts as diverse as the arrival times of photons at the retina and the numbers of seeds on patches of land. The simplicity of these examples belies a great deal of background required to grasp why the simplicity is notable; the nonexpert responds to their presentation with polite attention at best. Universality, in contrast to a disordered zoo of reasons behind things, is not as much of a draw as one might think. I will stress that this does not mean that we should avoid discussions of scientific elegance, just that it is dangerous to *begin* a lesson with this as the focus, rather than having elegance make an appearance later on.

Math is also ill-suited to sparking enthusiasm, for reasons already described, but it is worth elaborating on how audiences can be led toward engaging in mathematic thinking. Scaling behaviors, the functional forms relating forces, material properties, or other characteristics to size, time, or other parameters, allow one to make sense of all sorts of natural phenomena. The typical distance traveled by a diffusing particle scales as the square root of time, for example. Surface area and volume scale as length squared and cubed, respectively, with a long list of consequences for animal physiology (23–25). In these and many other examples, scaling takes a power law form. This form is nonintuitive to many, despite seeing exponents in secondary school classes and memorizing rules for use. Exercises in which students are led to devising explanations for rules and in which students graph, for example, areas and volumes of various shapes on logarithmic axes can help develop mathematic understanding and often foster epiphanies of mathematic reasoning.

## Biotechnologic frontiers

Contemporary advances in biotechnology are stunning in their import, and discussing the biophysical underpinnings is, I suggest, underexplored in the context of education and outreach. Molecular and cellular scale activities such as DNA packing, cytoskeletal dynamics, and membrane fluidity are well-recognized *core* phenomena of biophysics. Larger scale intersections of physics and physiology are also well appreciated, and in recent years, the biologic physics community has embraced the investigation of coordinated activities of many organisms, for example, the dynamics of flocks of birds; see (26). In recent years, technologies such as high-throughput DNA sequencing, organoids and organs on a chip, and CRISPR-based gene editing have revolutionized

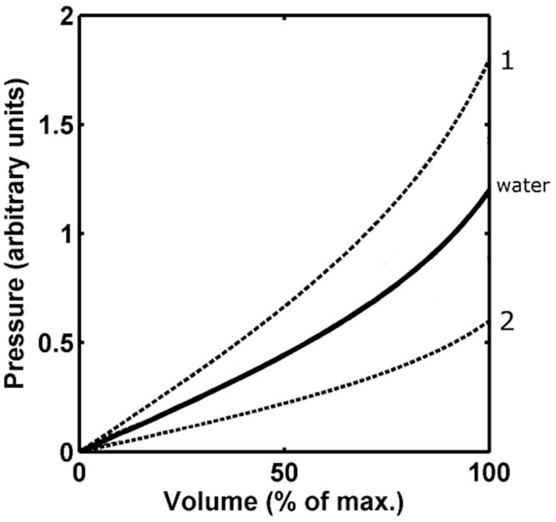

**Fig 1**. A final exam question from The Physics of Life, a course for nonscience major undergraduates. The graph shows pressure versus volume for lungs. The bold curve shows the pressure versus volume relationship measured by filling healthy lungs with water. Filling healthy lungs with air, we'd expect a curve like _____. Fill in the blank with one of the following choices: A. 1, because more work is required to create an air–water interface than a water–water interface. B. 2, because less work is required to create an air–water interface than a water–water interface. C. 1, because air is less dense than water, so it takes more work to pressurize with air. D. 2, because air is less dense than water, so it takes less work to pressurize with air.

what is possible for investigating, and altering, living systems. The discussion of recent biotechnologies, I would argue, is important for the engagement of general audiences and is inherently biophysical. It intersects the hooks noted earlier: these tools impact health and disease, are very current, and affect our relationship with the natural world. In addition, they highlight important connections between science and ethics (e.g., related to embryo selection) that are already relevant in real-life situations and for which a widespread understanding of the underlying science is crucial.

Accordingly, I emphasize genomic technologies, mainly involving DNA sequencing, mapping polygenic traits, and gene editing in my teaching (1, 2). One can connect these developments to more standard biophysical topics, such as the physical nature of gene regulation or DNA packaging presented in the first third. Though usually not presented as such, contemporary biotechnologies are a consequence of the physical character of biomolecules and of ways they are manipulated and driven with electric fields and encapsulated in emulsion droplets. Even the more abstract principles involved in, for example, understanding what is meant by statistical correlations between DNA sequence and height or the stochasticity in embryo selection, find mirrors in concepts such as random walks and Brownian motion. Further development of these connections will, I suggest, be valuable for education.

## Assessment

Assessment of learning is always challenging, especially in situations in which there are not specific, well-defined skills to assess but rather general conceptual understanding and qualitative shifts in perception. Compounding the challenge, what one really wants to know are the audience thoughts years in the future. Nonetheless, some rough idea of efficacy can come from exams, exit surveys, and course evaluations. From The Physics of Life course noted previously, I will give 2 examples of challenging exam questions related to topics noted earlier in this report that involve reading graphs and understanding biophysical relationships. The first, on the workings of the lungs, shows a graph of pressure versus volume for lungs, a stylized version of a graph of data from artificially inflated cow lungs that the students saw and discussed in class (27). The multiple choice question asks whether the pressure needed to fill lungs with air would be higher or lower that the pressure needed to fill with water and why (Fig 1 caption.) Approximately three-quarters of the class answered correctly. In another, short-answer question, related to biomechanics and scaling relationships, students were shown a graph of data they had never before seen (23) on tree diameter versus height, plotted on logarithmic axes. From this, they had to write a paragraph or 2 explaining how diameter and height are related, whether the data indicate isometric scaling (the same proportions of dimensions, regardless of size) and if there are similarities or differences with relationships between animal bone diameters and lengths discussed in class. Throughout the course, we stress that memorizing facts is not important, but rather understanding reasons and relationships is, and this philosophy carries over into exams. The student evaluation scores for course quality over 9 instances of the course are statistically indistinguishable from that of all general education courses offered by the University of Oregon's physics department between 2008 and 2019 (after this, evaluation questions and format changed considerably, making comparison difficult). For the high school day camp in physics and human physiology, numerous conversations as well as end-of-camp surveys indicate an expanded perception of what physics is and of its relevance to everyday life, as well as overall highly positive experiences.

## Future directions

Communicating biophysics to general audiences, whether students or the public, presents challenges but also the potential for major impact, changing how people view paths of study, opinions about biotechnologies, and the relationships with the natural world. I hope to have conveyed insights that, though perhaps idiosyncratic, may be of general use. It is worth thinking about how biophysicists as a whole might pool resources or work together to target particular, and hopefully large, audiences. Recently, the National Academies of Sciences, Engineering, and Medicine conducted the first ever decadal survey of biologic physics (28), generating a thorough and fascinating document that maps the state of the field. Among other recommendations, it calls for biologic physics to be integrated into the mainstream physics curriculum, at all levels of education. Similarly, we may aim for biophysics to become part of everyone's understanding of what physics and science are.

## ACKNOWLEDGMENTS

The author declares no competing interests.

## REFERENCES

1. Parthasarathy, R. 2015. "The physics of life," an undergraduate general education biophysics course. *Phys Educ* 50:358–366.
2. Parthasarathy, R. 2022. So Simple a Beginning: How Four Physical Principles Shape Our Living World. Princeton University Press, Princeton.
3. University of Oregon. 2022. Student Academy to Inspire Learning. Accessed 26 October 2022. http://sail.uoregon.edu.
4. Loewus, L. 2016. 2 in 5 high schools don't offer physics, analysis finds. Accessed 27 August 2022. https://www.edweek.org/policy-politics/2-in-5-high-schools-dont-offer-physics-analysis-finds/2016/08.
5. Wilczek, F. 2021. Fundamentals: Ten Keys to Reality. Penguin Press, New York.
6. Tyson, N. D. 2017. Astrophysics for People in a Hurry. W. W. Norton & Company, New York.
7. Tyson, N. D. 2022. Starry Messenger: Cosmic Perspectives on Civilization. Henry Holt and Co., New York.
8. Hawking, S. 1998. A Brief History of Time. Bantam, New York.
9. Hossenfelder, S. 2022. Existential Physics: A Scientist's Guide to Life's Biggest Questions. Viking, New York.
10. Munroe, R. 2014. What If? Serious Scientific Answers to Absurd Hypothetical Questions. 1st edition. Dey Street Books, Boston.
11. Munroe, R. 2022. What If? 2: Additional Serious Scientific Answers to Absurd Hypothetical Questions. Riverhead Books, New York.
12. Meadows, D. H. 2008. Thinking in Systems: A Primer. Chelsea Green Publishing, New York.
13. Phillips, R., J. Kondev, J. Theriot, H. Garcia, and J. Kondev. 2012. Physical Biology of the Cell. 2nd edition. Garland Science, London.
14. Nelson, P. 2020. Biological Physics: Energy, Information, Life. Chiliagon Science, Philadelphia.
15. Parthasarathy, R. 2021. Resource Letter BP-1: biological physics. *Am J Phys* 89:1071–1078.
16. Alpers, M. P. 2008. The epidemiology of kuru: monitoring the epidemic from its peak to its end. *Philos Trans R Soc Lond B Biol Sci* 363:3707–3713.
17. Lindenbaum, S. 2001. Kuru, prions, and human affairs: thinking about epidemics. *Annu Rev Anthropol* 30:363–385.
18. Pruisner, S. B. 1995. The prion diseases. *Sci Am* 272:48–57.
19. Lello, L., S. G. Avery, L. Tellier, A. I. Vazquez, G. de Los Campos, and S. D. H. Hsu. 2018. Accurate genomic prediction of human height. *Genetics* 210:477–497.
20. Mars, N., E. Widén, S. Kerminen, T. Meretoja, M. Pirinen, P. della Briotta Parolo, P. Palta, A. Palotie, J. Kaprio, H. Joensuu, M. Daly, and S. Ripatti. 2020. The role of polygenic risk and susceptibility genes in breast cancer over the course of life. *Nat Commun* 11:6383. https://doi.org/10.1038/s41467-020-19966-5.
21. Andrews, C. B., S. A. Mackenzie, and T. R. Gregory. 2009. Genome size and wing parameters in passerine birds. *Proc Biol Sci* 276:55–61.

22. Kapusta, A., A. Suh, and C. Feschotte. 2017. Dynamics of genome size evolution in birds and mammals. *Proc Natl Acad Sci U S A* 114:E1460–E1469.
23. McMahon, T. A., and J. T. Bonner. 1983. On Size and Life. Scientific American Library, New York.
24. Vogel, S. 1988. Life’s Devices: The Physical World of Animals and Plants. Princeton University Press, Princeton.
25. Schmidt-Nielsen, K. 1972. How Animals Work. Cambridge University Press, Cambridge.
26. Cavagna, A., and I. Giardina. 2014. Bird flocks as condensed matter. *Annu Rev Condens Matter Phys* 5:183–207.
27. Clements, J. A. 1962. Surface tension in the lungs. *Sci Am* 207:120–130.
28. National Academies of Sciences, Engineering, and Medicine. 2022. Physics of Life. The National Academies Press, Washington, DC.