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From Random Walks to Brownian Motion, from Diffusion to Entropy: Statistical Principles in Introductory Physics[1]

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Entropy changes underlie the physics that dominates biological interactions. Indeed, introductory biology courses often begin with an exploration of the qualities of water that are important to living systems. However, one idea that is not explicitly addressed in most introductory physics or biology textbooks is dominant contribution of the entropy in driving important biological processes towards equilibrium. From diffusion to cell-membrane formation, to electrostatic binding in protein folding, to the functioning of nerve cells, entropic effects often act to counterbalance deterministic forces such as electrostatic attraction and in so doing, allow for effective molecular signaling. A small group of biology, biophysics and computer science faculty have worked together for the past five years to develop curricular modules (based on SCALEUP pedagogy) that enable students to create models of stochastic and deterministic processes. Our students are first-year engineering and science students in the calculus-based physics course and they are not expected to know biology beyond the high-school level. In our class, they learn to reduce seemingly complex biological processes and structures to be described by tractable models that include deterministic processes and simple probabilistic inference. The students test these models in simulations and in laboratory experiments that are biologically relevant. The students are challenged to bridge the gap between statistical parameterization of their data (mean and standard deviation) and simple model-building by inference. This allows the students to quantitatively describe realistic cellular processes such as diffusion, ionic transport, and ligand-receptor binding. Moreover, the students confront “random” forces and traditional forces in problems, simulations, and in laboratory exploration throughout the year-long course as they move from traditional kinematics through thermodynamics to electrostatic interactions. This talk will present a number of these exercises, with particular focus on the hands-on experiments done by the students, and will give examples of the tangible material that our students work with throughout the two-semester sequence of their course on introductory physics with a bio focus.

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