Collaborative Research: Creating a Common Thermodynamics

A great transformation is taking place in university level biology education. Modern biology increasingly involves the interplay of tools and modes of thinking that are drawn from a range of scientific disciplines – chemistry, physics, math, and computer science. Leading biologists and organizations representing the biological community are calling for a reform of biology education that involves focusing less on memorization and more on the development of understanding and scientific reasoning skills.

Thermodynamics and the associated underlying statistical picture of random molecular motions are absolutely fundamental in biology. In order to make sense of biological processes ranging from respiration and photosynthesis in the cell to the survival and stabilization of ecosystems a good understanding of the concept of energy, its conservation, its availability, and its manipulation is absolutely essential. Furthermore, since biology is fundamentally about the generation, evolution, and maintenance of organization and structure, the concept of information and its statistical mechanical partner, entropy, also plays a critical role.

Students typically encounter the concepts of energy and entropy in introductory biology, chemistry, and physics classes. Unfortunately, these concepts are subtle and difficult to understand. Moreover, the approach taken to introducing these concepts in the three disciplines can be dramatically different. Often, different assumptions are implicitly made and the same concept used to mean different things in the three courses. This failure to coordinate raises severe barriers to students' development of a coherent understanding of these important ideas.

In this project we bring together education researchers who are also disciplinary experts in physics, chemistry, and biology as co-PIs. To this group we have added a powerful cadre of consulting experts who have agreed to interact with us and provide us with advice and expertise. We propose to bring together what is known about student difficulties on these subjects from research in physics, chemistry, and biology education, and to negotiate a common approach to thermodynamics with a team of educational specialists in the three disciplines. We will create a common literature survey and a set of modules for introductory physics. These modules will include text, homework problems, and in-class activities. Topics covered will be determined by negotiation but will at a minimum bring chemical energy, enthalpy and the Gibbs Free Energy, and diffusion, topics usually ignored in a physics class .

The modules will be developed in conjunction with education research on student attitudes and understandings of thermodynamics and statistical issues in physics, chemistry, and biology classes. The materials will be evaluated by careful usability testing and a pre-post survey. These materials will be widely disseminated and the results of our observations and testing reported at conferences and in the peer reviewed literature.

Intellectual Merit:
Physics tends to deal with highly oversimplified examples in order to permit students a complete understanding in a limited set of circumstances that can be imbedded in more complex phenomena and used as a grounding for developing an understanding of those phenomena. Biology necessarily deals with complex systems, but energy conservation and the second law of thermodynamics are fundamental constraints to those systems. Rethinking how to do thermal and statistical concepts in physics could have powerful implications for how physics and biology instruction are related.

Broader Impact
Although the topics reformed by this project only correspond to about 10% of current introductory physics classes, they are crucial for the inclusion of authentic biological examples into introductory physics. The results of the project could be transformative on the curriculum for training biologists and, not incidentally, pre-medical and pre-health care students.