Students’ Views of Macroscopic and Microscopic Energy in Physics and Biology

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Motivation: interdisciplinary science education

Recent reports on biology education reform* have called for more integration of physics principles into undergraduate biology and pre-med education.

As part of the NEXUS (National Experiment in Undergraduate Science education) project**, we are developing a new physics course for undergraduate biology majors, to integrate physics principles with biological contexts.

To integrate physics with biology, we need to investigate how students understand energy across the disciplines.

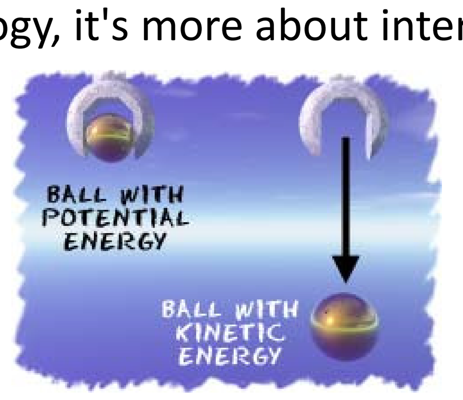
Energy concepts are central to both physics and biology, yet they can receive very different treatments in physics and biology courses.

“[F]or those [biology students] who do combine their study of natural science with physical science, the ideas that they are taught about energy appear remote from what occurs in biological systems.” (Gayford 1986)***

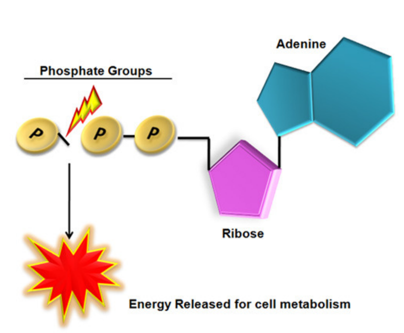
“Dennis”, the subject of this case study, is a junior taking introductory physics. He recently switched out of the biology major, but has completed the introductory biology and chemistry sequences.

Dennis perceives a disconnect between energy in physics and energy in biology, and between energy at the macroscopic and microscopic scales.

When dealing with energy, says Dennis, physics class “talks a lot more about physical objects, stuff like that, which you don't really talk about in bio or chem. You don't really talk about macro stuff…
Biology, it's more about interactions of molecules.”



Energy in physics = macroscopic



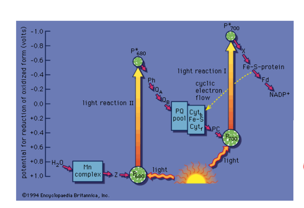
Energy in biology = microscopic

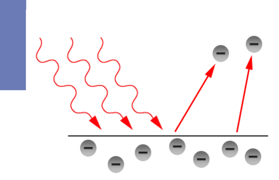
Dennis says that energy at the macroscopic vs. microscopic scales has “different units”, and therefore can’t be compared directly.

“I'm saying even if there were a way to connect the two, which I don't, I certainly don't, can't think of a way, I don't really think there would be a point in doing so.”

Despite claiming that they are disconnected, Dennis makes connections between different scales and disciplines when explaining phenomena in terms of energy.

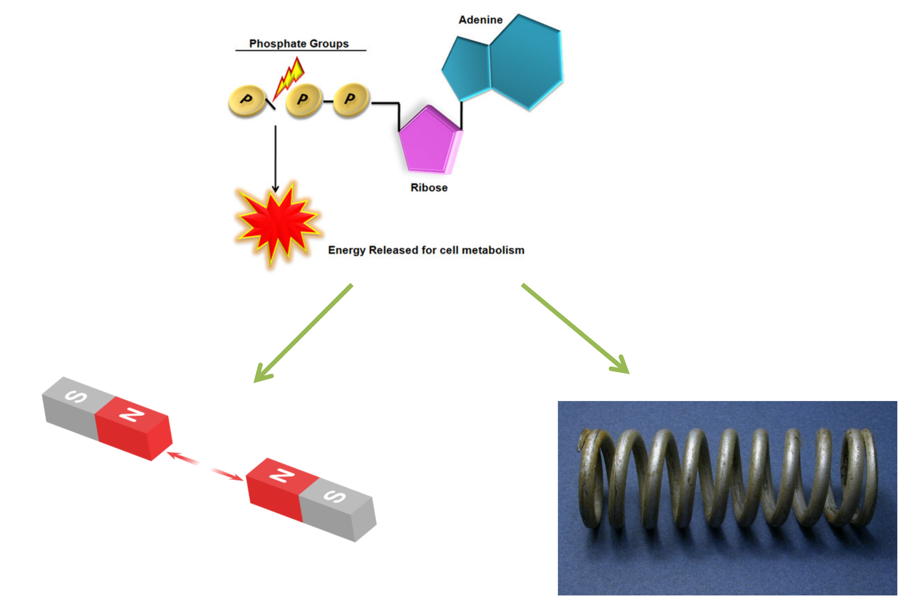
“I guess it would be electrons, is where energy is stored, I guess would be the moral of the story. Yeah. 'Cause I mean if you look at **redox reactions**, that's, you know, the movement of electrons. **Photosynthesis**, you know, you plug in a photon and, you know, you essentially plug in an electron, it bumps up a state. And you know, **solar power**, it's the same thing, the sun's photons hit the solar power, you know, it bumps it up, it catches the current, it **goes through a circuit**. That's what creates the energy. So I guess electrons would kind of be the current. The currency.”



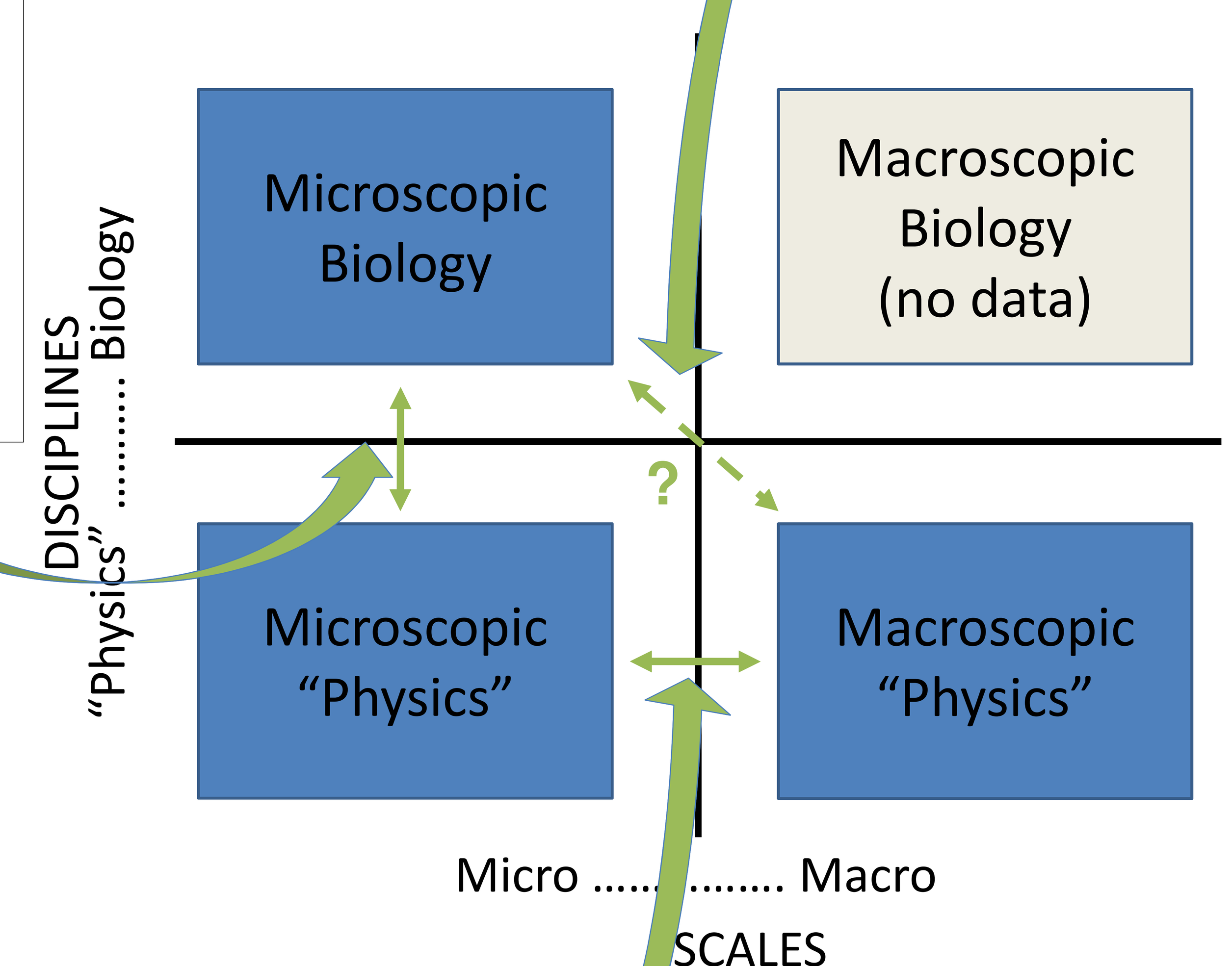


Dennis connects biology and physics (and chemistry) contexts, within the microscopic scale.

Explaining how energy is stored in ATP:
“So this is ADP and this is P, the bond between these two, these phosphorus, it's really strong in that this is really strong negative charges, so you push those suckers together, it's hard to do that, but if you do that, then you have a whole lot of potential energy, because you know, when two molecules are, you know, as soon as you know, **kind of like magnets**. If you shove two magnets together, you know, they have a whole lot of potential energy just 'cause, or **pushing in a spring** even, same deal, you know, you have a whole lot of potential energy, and as soon as you release that potential energy, the spring expands again. That's how work is done.”



Dennis connects a microscopic biology phenomenon to macroscopic “physics” phenomena, but only as an analogy. Here, he isn’t necessarily saying that “energy” stored in an ATP molecule is the same entity as “energy” stored in a spring.



“So I guess in the same way, with a cannon, you ignite it, and you **break the bonds** that, I guess, have a whole lot of energy stored up, 'cause that's what makes them explosive material as you break them, it converts the energy of that to a cannonball. Or to pushing the cannonball, and then the cannonball moves. So I guess energy is kind of imparted from explosive material to the cannonball. From … **chemical energy**, it gets converted into **kinetic energy** and that's a **cannonball** moving.”

Dennis connects the microscopic and macroscopic scales, within the “physics” (non-biological) context.

Discussion: What’s happening?

It may be easier for Dennis to cross one of these barriers (disciplines **or** scales) than to cross both at the same time.

But that’s not the whole story: Dennis demonstrates that he has the conceptual resources to make these connections, and does make them under some circumstances, but in other circumstances claims that it is not possible or useful to connect the different scales/disciplines.

Dennis may lack the **epistemological** commitment to a unified energy concept that experts have.

Because students may not integrate energy concepts across domains on their own, explicit effort may be needed to facilitate this integration.

References

* *Scientific Foundations for Future Physicians* (AAMC/HHMI, 2009), *Vision and Change in Undergraduate Biology Education* (AAAS/NSF, 2011)
** http://www.hhmi.org/news/nexus20110608.html
*** Gayford, C.G. (1986). Some aspects of the problems of teaching about energy in school biology. Int. J. of Sc. Educ. 8, 443-450.

Acknowledgements

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