

Students' Reasoning About Interdisciplinarity

Benjamin D. Geller, Benjamin W. Dreyfus, Vashti Sawtelle, Julia Svoboda,
Chandra Turpen, and Edward F. Redish

Department of Physics, University of Maryland, College Park, MD 20742

Abstract. We present case-study data of undergraduates describing the relationship between scientific disciplines. Rather than viewing biology, chemistry, and physics as existing in disconnected silos, or as overlapping only in narrow regions of common interest, these students exhibit a range of nuanced views about disciplinary relationships. Some students describe hierarchical arrangements that order the disciplines by degree of system complexity or by the scale used to examine a particular system. In other instances students want physics embedded in a context that positions its relationship to biology via analogy, or reference the way in which general physical principles like energy conservation or entropy maximization impose constraints on biological systems. We argue that these case studies illustrate the varied resources that students possess for seeking coherence across disciplines, as well as the potential barriers to interdisciplinary learning that such views might create when adopted to the exclusion of others.

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INTRODUCTION

In response to numerous calls for greater integration of physics principles into undergraduate biology [1] and pre-health [2] education, we have developed a two-semester introductory physics course for undergraduate biology students at the University of Maryland. The course seeks to break down barriers that can lead to the construction of disciplinary “silos,” and build coherence among the students’ experiences in biology, chemistry and physics courses. Particular emphasis was placed on disciplinary authenticity [3] and the construction of common models and languages for describing phenomena related to energy and thermodynamics, topics that cross traditional disciplinary barriers. The course was piloted during the 2011-2012 academic school year, with approximately 20 students enrolled.

A major research goal associated with this course is to examine the strategies that students bring to bear on problems and concepts that cross disciplinary boundaries. Research on interdisciplinary education has rarely focused on students’ own resources for seeking coherence across such boundaries. Indeed, it is an open question as to what “good” interdisciplinary reasoning even looks like, and how specific tasks and course messaging might influence the strategies that students employ. In this paper, we examine how students in the first iteration of our course describe the relationship between biology, chemistry, and physics, and how those views might inform further iterations of the course. We identify a number of student resources

[4-6] that have the potential to support coherence-seeking across disciplines.

METHODOLOGY

To get a sense of how students viewed the integration of biology and physics in the course, six case-study students were each interviewed between one and four times during the second semester of the Physics for Biologists course. All of the students in the course were either life science majors or pre-health-care students, and all had completed at least one year of biology, one semester of general chemistry, and one year of calculus. Interview protocols were designed not only to elicit discussion about how the course as a whole was being perceived, but also to promote discussion of specific task and exam content that the students had recently experienced. The interviewers were not course instructors, but did play a role in the development of course curriculum.

Data from interviews with four of these case-study students are examined in this paper. “Anya” and “Hollis” were enrolled in both semesters of the course, whereas “Gregor” and “Wylie” joined at the start of the second semester. While we do not claim that these students are necessarily representative of the class as a whole or the introductory physics population generally, we do see these examples as an indication that students may have varied and nuanced sets of resources for reasoning about the disciplines.

RESULTS

Students exhibited a range of nuanced views about disciplinary relationships during our case-study interviews. Some students described a *hierarchical* relationship in which disciplines are arranged by the spatial scale used to examine a particular system, or by the perceived complexity or level of abstraction associated with the disciplines. In other instances students describe a desire to see physics embedded in a context that positions its relationship to biology via *analogy*, seeing the explication of such analogies as a particularly useful step toward an understanding of unfamiliar physics. In still other instances, students reference ways in which general physical principles like energy conservation or entropy maximization impose *constraints* on biological systems. The hierarchical, analogical, and constraint-based views of disciplinary relationships are not mutually exclusive, nor are they exhaustive of students' views. There is overlap and room for debate as to which category best captures a particular instance of reasoning. Nevertheless, we believe that the general framework does provide a first-order approach to describing resources that students may bring to bear in an interdisciplinary science course.

The Hierarchical View

Several students describe a hierarchical relationship between the disciplines, often with physics at the bottom, chemistry in the middle, and biology at the top. Anya illustrated this hierarchy in great detail, producing a drawing in which each discipline was represented by a rung on a disciplinary "ladder." In discussing her own depiction, Anya describes the vertical axis of her drawing as representing complexity, with the top level (biology) involving quite complicated systems and the bottom level (physics) representing simplified and often idealized situations. For Anya, a persistent struggle in the course stems from attempting to bridge the physics level to the biology level. She feels that the gap between the two disciplines is at times prohibitively large and, unless she is given a justification for doing so, finds it unsatisfying to black box her knowledge about complicated biological systems in order to work with simplified physical models. Anya describes the difficulty she has in trying to "build up" a complicated biological system from what she is learning in our physics course:

"Physics is like very much just basic everything, and then that builds up to all these particles and all these things you have in chemistry and then you get

to biology... everything is just building from this [points to bottom] system after system after system to like really complicated things... So I think that we were just even trying to fill in the gaps here [between bio and chem] that we didn't know. We just jumped to here [points from physics to biology directly]. You don't have all this [waves across the whole spectrum]."

Anya desires more explicit explanations of disciplinary connections between rungs on her ladder. For her, it is desirable to focus on the connections between physics and chemistry first, since she sees this as a necessary preliminary step toward understanding the connections between physics and biology. Far from seeing the disciplines as living in distinct silos, Anya seems convinced that with enough time and effort one could in principle build a coherent framework in which each discipline is described by the discipline below it. She views that process as arduous, however, and later adds that even "expert scientists" might never have sufficient time to fully explicate the details of every connection in the hierarchy.

Gregor also describes the disciplinary relationships in a hierarchical fashion, expressing a belief that "all biology is just chemistry" and "all chemistry is just physics." Gregor sometimes describes levels on the hierarchy as indicative of the grain size at which a particular discipline focuses its attention [7]. In Gregor's view, one discipline is distinguished from another by both the spatial scale at which one examines a particular system, and by the degree to which contextual features can be ignored:

"Well I mean physics is micro and macro... but physics, yes, like I would say that it does look at things in like a stripped down sense. Not just in the sense that you're zooming physically into small scales physically but... you're talking about vacuums and things that don't exist. You just take out variables and context, whereas in other sciences it's more difficult to do that because you wouldn't see the phenomenon you're trying to investigate."

Gregor sees complexity as being abstracted away in physics to a degree that is not practical in biology. Later in the interview, Gregor cites examples meant to illustrate why it is inappropriate to apply the idealization strategies so often utilized in physics to the biological realm. In his view, doing so would mask the very features that are important in biological investigations.

The Analogical View

For Hollis, a salient feature of interdisciplinary learning is the use of physical analogs to biological systems. In one instance in the course, a biological cell membrane was modeled by a capacitor, both possessing at least superficially similar physical properties. This analogy affords Hollis a way of thinking about capacitors in a familiar context, one that she has studied numerous times before in her biology courses, but it also illustrates some of the limitations of the model:

“The capacitor with the two strips - this can be rolled up and modeled like a cell membrane. And I asked [the Professor] a question: ‘Would the positive side be like the phospholipid heads? Or the tail?’ Like I was confused as to how the capacitor model fits into like a cell membrane. So I mean I guess, it’s hard to visualize how it directly translates into a biological system... I’m more familiar with the cell membrane and how a cell works, as opposed to two strips of metal... since I’ve had more experience, more background about cells, it would be easier for me [using a biological analog] to get a picture that makes sense.”

The capacitor analogy not only allows Hollis to make sense of a capacitor’s properties in a way that is more meaningful to her, but it also allows her to more easily question the limits of the analogy itself. Her familiarity with the cell membrane affords her the opportunity to search for ways in which the capacitor model could be extended and the mappings could be made more clear, and in so doing she may actually gain a deeper appreciation for the modeling process generally.

Unlike the hierarchical view, in which one seeks to derive an understanding of biological systems via a series of deductive steps stemming from the underlying physical principles, an analogical presentation allows one to describe particular salient aspects of a biological phenomenon via a more direct mapping. Doing so has the potential to enhance understanding of both systems. The analogical view is by definition one that emphasizes the central role of modeling in the scientific process and, as we see with Hollis, does so in a way that may make the modeling process more accessible.

The Constraint View

A view of disciplinary relationships that emphasizes the ways in which general physical principles impose constraints on biological systems

provides students with another way of connecting physics to biology, and may do so in a way that addresses Anya’s concern regarding the large complexity “gap” between the disciplines. Students referred to this constraint-based approach in our interviews. Wylie, for example, sees traditional problems regarding energy conservation as biologically relevant because the same principles would be applied to any system:

“Yeah, so there are questions on the MCAT that are just ‘this ball is rolling down a hill, you know, what is its KE going to be at the end?’ So you know it doesn’t put that in a biology context, but it’s still a valid physics question... because the reasoning that would have applied to a biological setting would have been very similar to the reasoning applied to a physics problem.”

In this context, Wylie suggests that reasoning strategies involving attention to energy changes would be brought to bear in both the biological and physical problems. The problem of a ball rolling down a hill is still relevant to authentic biological scenarios because the energy conservation principle that one grapples with in solving the problem would constrain any biological system.

In another instance, when discussing the Second Law of Thermodynamics from a perspective of microstate maximization, Hollis becomes puzzled by an example that she sees as violating the Second Law. She had recently been discussing enzyme-substrate binding in a biology course and, after learning about microstates and entropy in her physics course, concludes that the enzyme-substrate analog binding “would be more entropically favored than normal enzyme-substrate binding.” She knows from her biology background that the substrate analog binding process should not be favored, so she begins to search for a way of reconciling the physical principle with what she knows to be true about the biology. Although it turns out that the confusion stems from a misunderstanding of the precise meaning of microstates, Hollis’ attempt to impose a physical constraint on her prior biological understanding is a productive instance of using constraint-based reasoning to bridge disciplinary barriers [8].

DISCUSSION

We see evidence in our case-study interviews that students possess a variety of resources for forming connections across disciplinary boundaries. We now turn to discussing some of the affordances and constraints these views have the potential to bring to

interdisciplinary reasoning. The hierarchical view that Anya describes makes it natural for her to value deductive, step-wise connections between physics and biology. This view has the potential to support connections among the disciplines in a way that would not be possible if she viewed the disciplines as existing in disconnected silos. At the same time, Anya's hierarchical view also leads to frustration as she recognizes that the full elaboration process could be untenably arduous. She states that even experts might not be able to make all the deductive jumps between physical laws and complicated biological phenomena, and this realization has the potential to discourage her from making similar attempts herself in the short term.

The analogical and constraint-based approaches to disciplinary border-crossing suggest an important possibility for addressing Anya's frustration in having to "jump" across what she perceived to be a large conceptual gap between physics and biology. Rather than working to fill in every step in the hierarchical chain, it may well be a more effective strategy to draw upon other resources that students possess for bringing physics and biology into contact. In modeling the cell membrane as a capacitor, for example, Hollis is able to leverage her substantial biological knowledge in a way that makes the capacitor analogy immediately meaningful. While the instructor's intent may have been to introduce the simple capacitor system as a step toward understanding a complicated cell membrane, Hollis' biological knowledge allowed her to work in reverse, as she used her understanding of the biology to map backwards onto her understanding of the physical system. In this way the analogy serves two functions: (1) to bring the physics and biology immediately into contact, without requiring a long deductive chain, and (2) to leverage students' prior knowledge about biology in order to explore the possible connections to a particular physical model.

Likewise, Anya's frustration could be alleviated by examining the biological phenomena she was trying to understand through a lens that emphasizes the role of physical constraints. No matter how complicated the system that Anya seeks to describe, and no matter how unlikely it might be that even experts could make explicit the connections to first principles, the fact that energy must be conserved could have been leveraged as a productive conceptual resource. Constraint-based reasoning, like analogical reasoning, is a resource that allows students to make interdisciplinary connections directly and without the need for extensive deduction. In turn, this allows the instructor to introduce rich biological contexts early on in the course, without the

concern that every detail of the biology must first be derived from simple physical laws.

The particular discipline-crossing resources that our students bring to bear is likely dependent on the nature of the problem being investigated and our student's sense of what constitutes a satisfying resolution in that moment. Indeed, most of the students we interviewed refer to more than one of the views mentioned in this paper at one time or another during the case studies. Each view of disciplinary relationships comes with its own affordances, but, as was true for Anya, adopting any single one of these views to the exclusion of others can be unsatisfying. Our students are likely to be most productive when they recognize different views of how the disciplines are connected, and can selectively bring to bear those different views at the appropriate moments.

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REFERENCES

1. National Research Council (US). Committee on Undergraduate Biology Education to Prepare Research Scientists for the 21st Century, *Bio 2010: Transforming Undergraduate Education for Future Research Biologists* (Nat'l Academy Pr, 2003).
2. Scientific Foundations for Future Physicians: Report of the AAMC-HHMI Committee (AAMC/HHMI, 2009).
3. J. Watkins, J.E. Coffey, E.F. Redish, and T.J. Cooke, *Phys. Rev. ST Phys. Educ. Res.* **8**, 010112 (2012).
4. D. Hammer, *American Journal of Physics* **68**, S52 (2000).
5. D. Hammer and A. Elby, *Journal of the Learning Sciences* **12**, 53-91 (2003).
6. L. Louca, A. Elby, D. Hammer, and T. Kagey. *Educational Psychologist* **39**, 57-68 (2004).
7. B.W. Dreyfus, B.D. Geller, V. Sawtelle, J. Svoboda, C. Turpen, and E.F. Redish, *AIP Conference Proceedings*, PERC 2012 **submitted**, (n.d.).
8. The constraint-based view is not necessarily unidirectional. Throughout the course, instances arose in which students attempted to impose biological constraints on physical systems. Often these constraints related to biological "purpose" or "function," as when students would suggest that the protein-transport duties of a cell membrane must be reflected in whatever physics was used to model the membrane.