Interdisciplinary research and the undergraduate biology student

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With scientific research becoming more interdisciplinary, it is important to consider changing the way we teach undergraduates about science.

Recently much has been said about the need to remodel undergraduate biology curricula[1–4]. The reasons are sound. Research in developmental, cell and molecular biology has been radically transformed by new technology over the past 25 years. New instrumentation, automation, micro-miniaturization and parallelization, along with massive data sets and the computational analysis methods necessary to digest them, are creating profound change. And yet, the teaching solutions of 25 years ago remain in wide use by all but the most creative teachers. For most of us with combined research and teaching responsibilities, the sense of urgency we feel to keep our research blades honed has no real correlate in our teaching life.

For those of us who want to integrate research and teaching at the interface of biology and engineering, the target keeps moving. As interdisciplinary research funding increases, a new, more collaborative research practice seems ready to supplant the 'one PI, one laboratory' model. The transformation of biomedical research by automation and computation is hastening this along, as many new instruments are now priced beyond the budget of the typical laboratory. Interdisciplinary research also requires extra effort on the part of the PI. Learning unfamiliar jargon, knocking the rust off of long-dormant math skills, and understanding the cultural vagaries of academic or company life in other disciplines take more work, and this places additional pressure on teaching time. This challenging transition promises to put even more distance between research and teaching. Although it can be predicted that research will become more interdisciplinary, forces that constrain teaching to be strictly disciplinary will remain strong.

"I don't know what it does, but the data look great!"

If we believe that the best research is sustained by excellent teaching and that the best teaching includes rapid transport of research-based thinking to the classroom, then we ought to admit that devoting attention to undergraduates will eventually accelerate research. At this time, most undergraduate biology students are not engaged in a curriculum that prepares them to think like interdisciplinary researchers[2,3]. It might be imagined that undergraduates are more malleable, and thus more receptive to interdisciplinary thinking. But the seeds of disciplinary entrenchment are sown in undergraduate classrooms. Time spent unlearning these too-disciplinary habits and prejudices is part of the work required to become an interdisciplinary thinker. What can we do to encourage interdisciplinary thinking in our undergraduate students from the start?

To explore this question I have been running an experimental undergraduate research laboratory class with the support of the Howard Hughes Medical Institute (HHMI) professors program (http://www.hhmi.org/research/professors/). In this laboratory class, which runs continuously like any good research-based program, I try to create an environment in which undergraduates majoring in computer science and bioinformatics work together with molecular, cell and developmental biology majors. A 1,200 square foot teaching laboratory has been converted for this purpose and is equipped with servers, a microarray spotting robot, an array scanner, a real-time PCR machine and other toys, as well as standard molecular biology

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equipment and materials. I have a number of diverse projects for them to explore, primarily high-risk and technology development efforts, or early-stage technology application ideas that require analysis and validation.

In many ways this little room models the Janelia Farm concept[5] at the undergraduate level. It's a place where similar 'metabolic' activities happen on a less grand and more decorative scale, a kind of Janelia flowerbox. Already some very interesting things have emerged that (of course) will require further testing and assessment. But it seems clear to me that the idea that we need not be concerned about interdisciplinary thinking at the undergraduate level is wrong. In fact there are numerous traditional practices that work against interdisciplinary thinking in early and insidious ways. Some of these disincentives are strongly practiced and may be hard to overcome, as they are traditions of the undergraduate experience. Others could be countered with efforts to encourage students to reach across their experiences and connect ideas more broadly. There are many opportunities to teach students how to remain open to adjacent disciplines before they learn otherwise. Below are a few observations that might benefit from more systematic analysis.

I become my major

After "what's your sign?", the question heard most often on campus is "what's your major?" Admissions officers ask it, advisors ask it, parents ask it, and peers ask it. And students ask themselves. For many, the choice of a major is tied up with their own process of self-definition, and can be less about what they want to learn than about who they want to be. The process of choosing a major is important for a variety of reasons. It helps students structure a course of study, provides an area for focused study while ensuring sufficient breadth, allows campus planning for resource allocation, and launches careers. But as it provides students with a sense of identity about their scholarship, it also too often identifies what the student is not going to do. The darker side to choosing a major is that it begins the process of disciplinary allegiance, and this leads to an expectation of limitations that may not be necessary.

Part of this is simple human nature. The need for identification with others like us is one of those deeply primitive things that no number of editorials will erase. The trick is to make the students aware of how the process of choosing may limit their own view of their true interests and potential. It follows that the best time to make this point is when the decision on a major is being made. If we can encourage students to see this choice as a reflection of what they want to learn, without viewing it as a decision about who they will be for the rest of their lives, then interdisciplinary thinking will come more easily to them later. Clearly, the major is an inextricably entrenched feature of undergraduate education around the world. It should be far easier to construct a more interdisciplinary biology curriculum than to change how we view the traditional major. But it seems likely that interdisciplinary thinking will develop more easily for our students if we cultivate the view that selecting a major doesn't involve an irreversible intellectual step away from important topics.

If it doesn't count toward my degree...

Once the major is chosen, the degree requirements become apparent. For majors in the molecular and cell biology area, with a large number of course requirements and an inviolate prerequisite structure, getting it all in can be constraining. This was recently brought to my attention when my engineering colleagues Josh Stuart and Peter Schattner launched a course to teach the computer programming language Perl and its biological applications to biology majors lacking any previous programming experience. My sense was that this course was exactly the thing for the graduate student or postdoc of the future to have under his or her belt. I talked it up in the undergraduate laboratory class and more than half of the biology students in the group bought the idea. I personally believe such a class should be required for all biology majors—not so they can do their own programming, but rather so they understand how computers are used to study biology.

A problem arose when they discovered that (as it was a new course) there was no mechanism to count it toward their degree. Several students balked at this point, as they could not afford to take an extra course and graduate on time. (For a variety of complex reasons, a substantial fraction of University of California students take four years plus one term to graduate, and this costs them extra money and time.) We talked about curricula, how they evolve, and how requirements in place today represent the needs of the past—some of which are still appropriate and some of which may be less important—and that their goal should be to learn for their future. In recognition of the fluid nature of higher education, most universities have a petition process that allows substitutions. Before the petitions could be approved, the amount and type of work and its 'equivalence' to a molecular biology elective needed to be determined. In this case, the course was considered equivalent to a 'laboratory' course, as it required hands-on activity and analysis, and had a practical character. Thus credited, the students happily took the risk, and the class.

Playing nicely with others

One day in the laboratory, two team members were chatting when a biology student happily suggested an approach to a problem, and a bioinformatics student responded in a sweetly mocking tone that it was a good idea, but that "in order to do that you'd have to know something about computers." Apparently some line had been crossed in their relationship and boundaries were gently being reestablished. This and similar chatter I have heard suggest to me that in interdisciplinary research it may be more important to know simply how to communicate with someone in another discipline than to know that discipline intimately. I have found this to be true in my own interdisciplinary efforts, and it is already observable in undergraduates from different majors who work together. Identity and roles are established. Value systems and language differ. What constitutes a contribution, how results are communicated, and how credit is apportioned are different in different fields. Ultimately the best science will come when interdisciplinary team members can address the same question in a coordinated fashion using diverse approaches. But before that can happen, culture gaps must be breached, communication must take place, and some roles must be established.

I have tested this a little in both cultural directions. Each bioinformatics student is encouraged to get directly involved in wet-laboratory experiments, usually a simple PCR reaction followed by agarose gel electrophoresis. Most can stand to do only one or two gels before going back to the keyboard, but a few really do enjoy it. At the very least, they learn the challenges and labor necessary to produce even a small wet-laboratory result. By the same token, the biology students get some programming experience in the Perl class, and most have not left the bench for the keyboard. But each side learns what the other is up against. Each side learns the physical demands and time constraints of the other's activities and some of the language, challenges and rewards of what the others do. This kind of cultural exchange is exceedingly valuable in their team efforts as each has more appreciation for and patience with their teammates. Although it may seem that this activity ultimately more strongly reinforces roles and constrains the activities of individuals, it actually broadens experience and seems to make better interdisciplinary teams.

Beige box syndrome

Growing up with a dad who is an electrical engineer did not create for me any special attraction to computers or electronics. But my dad fixed every electronic item in our house, multiple times if necessary (as was often the case), and this gave me the opportunity to see the interesting guts of these things splayed about. Thus, although I have never completely understood how they work, I have never been afraid to open them up and look inside, especially if they are already broken (and also unplugged). The electronics industry no longer builds things that can be opened up and put back together easily, so our children have a harder time becoming exposed to the inside of the box. Perhaps this is safer, but I believe this has had a negative effect on the relationship between people and machines, leading to fear of the box.

How then will biology students learn to think about instrumentation? The current state of affairs seems to indicate that it is best they simply call the tech support hotline. We probably all have made the same observations regarding new instruments that have come along. Oligonucleotide synthesizers, DNA sequencers, laser scanning imagers, colony pickers, microarray scanners and microarray printers have been hatched as large bulky machines with tubes and wires everywhere, bolted to vibration isolation tables, filling substantial parts of the rooms they occupy, and priced beyond the reach of most laboratories or departments. After commercial metamorphosis we find them as beige boxes priced almost within reach of the average laboratory. Biologists may be especially happy not to worry about instruments, as although their training may demand that they open frogs, it rarely demands that they open machines. But if you see only the box, and you can't open up the box, how are you going to conceive of an instrument that does for you what you currently do with your hands, or does it faster and in parallel on more samples than you can imagine?

I wanted to observe undergraduate students working in the laboratory with an unboxed instrument, and the microarray printer, built during a summer course taught by Joe DeRisi, does nicely. It is finicky enough and has enough exposed cables that it cannot be described as refined, and it is big, bolted to an isolation table, and there are places you shouldn't stand while it is running. There is not a spot of beige on it. Of course instruments like this need carbon-based units as essential components. We have Lily Shiue, our expert arrayer technologist, to mother this big baby, and to explain to us its care and feeding. But the students have responded very well to the opportunity to work with this machine, even when it means staying up all night. Unfortunately, there is not much relevant to instrumentation in the current biology curriculum, and most of the students who take jobs in the biotechnology industry see and operate such instruments only after they graduate. Biology curricula ought to include something more concerning the operation, capabilities and limitations of instruments, perhaps through connections with analytical chemistry or physics.

Back to the future

What can we do at the undergraduate level to enhance the success of students in the interdisciplinary research of the future? Emphasizing the major as a mechanism to explore an area of interest rather than a lifelong vocational commitment may help students retain their interests in multiple disciplines. Revolutionizing the curriculum seems impossibly political and laboratory-intensive, but where special new courses can be offered, every effort should be made to allow them to satisfy requirements. An important common language that allows interdisciplinary communication is math and statistics, and in these areas biologists often bring rusty skills[2,3,6]. It may not be necessary to overhaul the entire biology curriculum if appropriate courses in statistics, beginner programming, and instrumentation are available and can satisfy existing requirements. Research experiences in which undergraduates can be members of an interdisciplinary research team should also be cultivated, as it is widely held that doing research has a profound impact on undergraduate learning.

The above recommendations are simple to implement at the grassroots level. On the part of those of us engaged in research and teaching at research universities, they ask only that we stay aware of the changes in our field, and recognize when interdisciplinary opportunities become apparent. Even if we are not engaged in interdisciplinary research ourselves, we can advise our students to keep their minds open, challenge them to look ahead to a time when they will lead, and support a more rapid evolution of our curricula so that important new courses survive long enough to become established. Hopefully these ideas are practical enough that we can all get started right now, without having to write another grant.

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