

INTERVIEW

Darcy Kelley: Pioneering the Frontiers of Science Education

By Julie Ruble

Biology Department and Program in Neuroscience, Davidson College, Davidson, NC 28035



Darcy Kelley, a professor at Columbia University, has been a HHMI Professor since 2002. The HHMI Professors are innovative individuals recognized for their dedication to making science education more rewarding for undergraduates. Dr. Kelley recently entertained and educated attendees of the 2007 Symposium for Young Neuroscientists & Professors of the Southeast (SYNAPSE). Before her engaging keynote address, I had the privilege of asking Dr. Kelley about her career as a scientist, including her development of Frontiers in Science, a required course for first-year Columbia undergraduates. The course covers current research and major issues in science (such as evolution and the beginning of the universe) to give incoming students an exciting first look at the field. Ultimately, Dr. Kelley is dedicated to reaching undergraduates with the message that “science is cool.”

JR: Do you remember any experiences in your early science education, as either a high school student or an undergraduate, that sparked your excitement about science?

DK: I was a big reader when I was a kid, and one summer when I was young we had summer reading lists. I

somehow persuaded my mother that I was supposed to read every book on that list. Among the books that we got was a book called *Nobel Laureates in Science and Medicine*. I remember reading about the experiments and thinking of other experiments to do, and I think that really hooked me on it. I was then about 11 or 12. So I came to science through reading. I didn't go to a school that was very strong in science; it wasn't weak, but it wasn't particularly an emphasis. They all thought that I was going to go into English!

At that time—it was a long time ago—the Russians had launched a satellite called Sputnik, and the United States was afraid that it was going to fall behind in the race for Science. And so the National Science Foundation set up these summer science institutes for high school students. I got into two: one in Chemistry at Mt. Holyoke and one on the biological basis of behavior at Grinnell College in Grinnell, Iowa. I didn't know that behavior *had* a biological basis, so I decided to go there. And that was kind of the determinant event; before that I wanted to be in medicine and after that I wanted to be a scientist.

JR: You've referred to the process of writing scientific papers as “telling your story.” Do you feel strongly about science being a creative enterprise?

DK: I do. I think that people's ideas about science are completely mistaken. They think that you do an experiment and the data shriek at you, “This is what I mean!” But you know, if you've ever done an experiment, particularly at schools like Davidson where you really get *good* research experience, that the data never shriek at you what they mean. You have to look at them and try on a number of different stories and see what story fits the data best. Most people don't think of science as a creative activity, but I think it's one of the most deeply creative activities. Part of my goal is to change cultural perceptions of science; we're not all geeks with pocket protectors made out of plastic, right? There are some novel ways of thinking that we can contribute. I think about things the way scientists think about problems and it seems to be a great shame that everybody can't think that way, because it's a wonderful way to go out and appreciate the universe. I'm bringing that message as well.

JR: Speaking of delivering that message, *Frontiers in Science* is a required course that you developed for first-year students at Columbia University. What was your primary goal in designing the course? Can you talk a little about the idea and the impetus?

DK: I was on the Committee on Science Instruction and we decided one year that we were going to look at the courses Columbia students took to fulfill the science requirement, which at the time was the following: two courses in one department for depth and another course in a different department for breadth. What we discovered was that typically the student was very depressed. They'd come to Columbia and want to be pre-med and they'd take Chemistry and fail, and then they'd take a year of Math. I mean, this just didn't strike us at all as an adequate experience with science for someone who's supposed to be graduating as an educated person. So the head of the committee, astronomer Jacqueline van Gorkom, and I were sitting one day with our friend, astronomer David Helfand, and we said to David, "You know, we've been talking about possibly developing a course that kids could take in science." We thought about various things; we centered on light (there was a Stanford course on light). David said, "You know, I had an idea fifteen years ago for a course – kind of a 'great ideas in science' course." And Jacqueline and I looked at each other and said, "Great! Let's do that." So, from this conversation about five or six years ago came the impetus for *Frontiers in Science*. And the course really has two goals. One is to teach the ways you'd think about problems if you were a scientist. They're not so hard, but they're a set of good intellectual tools that help you with thinking critically about issues. And the second goal is a more cultural goal: it's to show that science is cool. The way we do that is to break the pyramid. Instead of having to take 42 million preparatory courses so you can finally take the cool course in quantum mechanics or evolution of language or the fate of the universe, we bring current science into this first year course so that it really is "frontiers in science." So those are the two goals: science is a way of thinking and science is cool.

JR: How did your experience as an undergraduate and as a scientist lead you to believe that a course like *Frontiers in Science* was necessary?

DK: Well, I think it was because I had such a *good* experience with science. I never had the feeling that it wasn't something I could do. I mean, I'm not an intrinsically talented scientist: I'm not a math whiz, I'm not incredibly adept in the lab, I had no extraordinarily natural talents for science. But I just love it; I think it's one of the most fascinating things you could ever study. And in science, I think, given a certain minimal level of intelligence, the desire is all. And it's been incredibly rewarding. It's really fun to do science; it's wonderful to learn new things. So the feeling that there were a huge number of students being shut out from that experience is one of the things that motivated *Frontiers*.

I have a favorite writer, Ellen Gilchrist, and she often uses scientific metaphors in her work. She has a collection of short stories called *Light Can Be Both Wave and Particle* and I was thinking, if you never hear of that idea or think about it rather deeply, how would your writing be? Would you be able to express yourself as creatively without knowledge of this very powerful system of metaphors that

comes from the knowledge of the world? So I just thought we were kind of shutting kids out of this source of enjoyment. And I think that's propelled a lot of thinking about *Frontiers*.

What I *didn't* realize when I started *Frontiers* was how much fun it would be to teach as a faculty member. When you're a scientist, you get channeled into narrower and narrower and narrower paths. You become the total expert on something—frog songs, God forbid—and so along the way you give up knowing good stuff about other things. I never took any geology, never took any astronomy. I took a year of physics, but I didn't take quantum mechanics. And so to be teaching with people who will, in fact, teach you as a teacher in addition to teaching the students some of the very neatest ways of thinking about the universe is a lot of fun. And the faculty are very devoted to *Frontiers* in part because it is so much fun. It's fun to learn new things in the other sciences.

JR: What's been the response of Columbia's faculty to *Frontiers in Science*? What about the response of the students?

DK: Well, I had a very subversive goal with *Frontiers in Science* — one of my goals was to try and change the faculty culture. Typically at an R1 university (not all of them, but many of them), teaching is devalued. In some sense it's inevitable; at an R1 university their main goal is to do research. Their prominence, their power, their position in the academic constellation comes from that. And there's always been the feeling, which has some basis in reality, that teaching detracts from research. It is very hard to do both things at once. But the goal of a scholarly and academic enterprise is not just the *uncovering* of new knowledge, but also the *transmission* of new knowledge. And this is particularly true within a university that has undergraduates. Teaching is rewarding and an important thing to do for society. So I had this subversive goal.

The goal ended up being reasonably well met because of the fact that *Frontiers* is a lot of fun to participate in. By chance, and probably by design as well, the faculty that started out pioneering in *Frontiers* was among the very best faculty that we have in the research area of Columbia. The fact that they're so good has led to a situation where people are actually interested in teaching in *Frontiers*. We're very choosy about who we let teach in *Frontiers*; you have to be charismatic, a gifted public speaker, you have to be, if at all possible, an active researcher. You also have to be somebody who's very interested in a multidisciplinary or interdisciplinary approach to science. Showing off the best faculty works very well and has had a kind of snowball effect. We now have a brown bag luncheon on teaching, which people go to — it's quite incredible. I wouldn't say that teaching was elevated to the pantheon within science instruction that it otherwise might've had, but it's had a big effect.

A great example is the Chemistry Department. When we started out in *Frontiers*, we went to the Chemistry Department and one of the senior members of the Chemistry Department wrote the Vice President a letter

and said that *Frontiers* would be instituted over his dead body, that it was impossible to teach anything interesting to 18-year-olds. But this year I got an email from the chairman of the Chemistry Department in which he said Chemistry was too important *not* to be in *Frontiers*, and *Frontiers* was too important *not* to have Chemistry. Boy is that a sea change; over four years they went from being adamantly opposed to trying to do this course to being very interested in doing the course. And partly it has to do with the quality of the faculty. So it's had a quite a big effect upon the faculty, although, as yet in relatively small numbers — I wouldn't say it changed everybody's minds.

With the students, it's much less clear. There's a very strong cultural antipathy to science in the culture-at-large. It's particularly true at Columbia, which is a humanities-oriented place. The kids hate that *Frontiers* is so different from their high school science. They have to think. There are kids who can really get turned on to science that had never considered it before, but there are also kids who come in hating science and hate it even more when they leave. On the other hand, they all know that they can do it with reasonable encouragement. It builds within their lexicon and within their constellation of intellectual tools a set of analytical abilities that they wouldn't otherwise have. So I don't think I'll know what effect it's had on students for maybe ten or fifteen years, because I think it'll take that long for people to think back on what they've learned and might otherwise not have learned, and realize that they can think about things now that they couldn't then.

The other thing is, we're not rigid in how we do this. It's so incredibly hard to teach *Frontiers* that we'll take a good idea from anybody. We spend a lot of time talking to students about more effective ways to do it. Often they want us to teach a course that is the interface between science and society, but they have other courses like that. They don't have any *real* science courses. We're out to empower people with intellectual tools, and we want them to have real science tools, and that's probably the hardest part of the course. So time will tell; the course may fail utterly. I think it's boring to do an experiment that can't fail, so I'm simply thrilled with the idea that it could fail.

The biggest danger of the course is that it will dwindle. That in order to staff the course, we'll have to staff it with people who aren't as good as it is now, and that the whole thing will just kind of wind down in some way. It's a sort of fact of life; these things do happen. Right at the moment, it's acquired somewhat of a life of its own. David and I are trying desperately to make sure that other people take it on that are capable of doing it so that it acquires a culture. We work within a culture that will support it in the core curriculum, so I think there's some hope. But there's no doubt it's a difficult experiment fraught with dangers and of uncertain outcome. Those are the most fun things to do.

JR: You've decided to create an online database of course materials, *Frontiers in Science Online*. How do you think such a web resource could affect undergraduate education (or what effect do you hope it will have)?

DK: The initial motivation for *Frontiers in Science Online* was a bit selfish. We put this huge amount of effort into developing these materials. *Frontiers in Science* is a five-year experiment; it could fail, the course could end and we'd go back to what we had before or something different. And I thought that the materials that we developed were useful and that other people would like to use them. I wanted to have them available, sort of like publishing a paper. So part of the goal of *Frontiers in Science Online* is to take all the stuff that we've developed and post it and get other people to post their cool stuff so that we can all have more resources for teaching, because teaching's one of the hardest things that we can do.

I also came to realize that a collaborative experience in teaching is very enjoyable. At a research university, you almost never talk about teaching with anybody. It's not a highly valued activity. You talk about research a lot, but you just never talk about teaching. But in *Frontiers*, there's a large discussion going on, both in the faculty meeting and online. We do all the materials together, we critique each other's lectures, and we create a sort of community of researcher teachers that's really a lot of fun to be part of and has that same kind of generative aura that a community of research scholars would have. So the other goal of *Frontiers in Science Online*, which has a big community discussion board, is to draw more people into that by creating a web-based resource where people can correspond.

JR: What is the most important advice you could give to neuroscience educators?

DK: I think you have to always think of the big picture. We become fixated on what we know a whole lot about. You know, the world of growth hormones and growth cone extension or the world of long-term potentiation and learning. What we're doing is we're focusing on a small part of the whole when the bigger portion is what drew us initially into science. So I think one of the things we have to do in neuroscience education is keep the big picture in mind: what is the brain for? What is the function of the brain? How would you think about it in a larger way and then how can you take those larger metaphors, neural circuits, neural networks and so forth, and bring them down to the level where the individual components are studied in a way that's very compelling and important for the larger function.

It's both important in your research and it's important in your teaching. It's much more gripping to students if there's a story — not only stories you tell about experiments, but also stories you tell about the brain and the way the brain decodes the world and the way the brain produces movement and ultimately the way the brain thinks and feels and so forth. These metaphors are very powerful and they help you teach. I think it's a big fallacy to deny the romance of what you do. You lose your ability to engage students emotionally when you do, and then you also lose what attracted you originally to the topic. If you try to be too dry and factual and precise, you lose out. Not that you should be imprecise or wrong or anything, but you

should never deny the attempt to look at some of the bigger pictures. So that would, I'd say, be my biggest piece of advice: not to lose the big picture for the small.

JR: Turning now to some of your current research, how did you become interested in *Xenopus laevis* as a model organism?

DK: I became interested in *Xenopus* for a kind of funny reason. I was interested in the origins of sex differences in behavior, and part of that came from being a woman scientist, which was even rarer then than it is now. I was interested in how the sexes might approach problems differently and whether there were sex differences in the brain. While I was a student at Grinnell in Iowa, I did a paper for my freshman Biology class and I read this book called *Sex and Internal Secretions*, which is all about steroid hormones. I became fascinated with the idea that hormones could carry the message of gender or male- and femaleness to cells in the body.

So when I went to grad school I worked in the lab, doing neurophysiology and staying up very late at night into the wee hours of the morning, which is not my style. The head of the lab said that I might be interested in working on this funny animal that, if you grew its tadpoles in estrogen, they were all female, even though half of them were genetically male. Thus you could test the idea that maybe there was a genetic contribution to the sex of cells as opposed to a purely hormonal contribution. So I grew all the tadpoles in estrogen and at the same time I was treating females with androgen to see what effect it had on their behavior. It was kind of interesting. Once you treated adult females with male hormones, they all behaved exactly like males and clasped other females and you really couldn't tell them apart. Meanwhile, all of my estrogen-treated animals died one weekend when the water was static in the pipes, which were full of copper. I changed their water on Monday and that was it; the poor tadpoles were history. Luckily by then I had the answer.

And so I became very interested in the question of what the mechanisms were by which hormones change the sexual differentiation of the brain; how did you sculpt a male and female brain? *Xenopus* is a great system in which to work on this question because the vocal behavior of the two sexes is very different, so you have a very nice behavioral readout. There is a good neural network that you can work on and you have the real ability to go after the cellular and molecular basis of it.

JR: As you started to look for a genetic basis, is that why you started to use *Xenopus tropicalis* more?

DK: One of the real advantages of *Xenopus* is that it's an NIH model organism. *Xenopus* has been really an engine of discovery for molecules that are important in development. It's a very good animal assay system for molecules that shape the embryo, that determine the anterior-posterior axis – all the very early events that are determinative in cell fate in the developing embryo. But all these developmental biologists developed a case of

genetics-envy. One of the first steps you can take nowadays along that road is to get sequence information. But *Xenopus laevis*, which was the big laboratory animal for many years, is a pseudo-tetraploid. The species hybridizes with other species, and then you get new species, so you end up with animals that have two parental genomes; it's quite incredible, sort of like plants.

There's just one diploid animal in the whole group, and that's *Xenopus (Silurana) tropicalis*. I started working on them because of that, and as it turns out, their vocal behavior is much more difficult than any of the other frogs', but we can still use the genetic information from *tropicalis* to go back and work on *laevis* and other members of the group. So it's been fantastically useful. And it got me interested in the question of how songs and the preferences for songs evolve, because there are a lot of frogs in this group and they're hundreds of millions of years old; it's quite fantastic, they're a very successful group. They all look alike, but they all sing those different songs.

JR: Why does the neurobiology of vocal communication interest you?

DK: I think the nice thing about vocal communication is that you get to study not just one brain, but two. Your brain is being changed forever by this interview and so is mine, right? That's the way it works. And if you think about it, it's an incredibly abstract thing: I'm creating these sounds in air very fast, and you understand every single word I say. The rate of information transfer is incredibly rapid. I can say to you, "Say 'please' to me," and you say "please." There's no gap between the auditory stimulus of "Say 'please' to me" and your ability to reproduce and produce that "please" sound. It's not like in the retina or in a simple reflex circuit where the muscle contracts if it's stimulated. There's a big and very rapid computational process that goes on. Understanding the interface between what's heard and what's uttered really lies at the heart of many interesting problems, including human language. And yet we know very, very little about it. So it seems to me that if you started with a system that had a very powerful form of vocal communication, which *Xenopus* does, that was in a very simple form but still highly selected for, then you would stand a good chance of uncovering the rules by which hearing is turned into utterance. So that's basically my goal: to sort of understand the basic rules by which the auditory input gets transformed into vocal output. And *Xenopus* is this great system because they have vocal dominance: males can make each other shut up (they have some vocal tools that are very cute) and females can either turn males on or shut them up. And females for some reason don't communicate (as far as we can tell) vocally with each other. So they have a complex vocal communication system that's different by the sexes but specific for context and is very powerful. It's a good system to work on; it's very robust and very interesting.

JR: From the exciting new *Frontiers in Science* course to your work with vocal communication, your experiences are sure to motivate and encourage

neuroscience educators. On behalf of JUNE readers, thank you so much for sharing your time and your vision for undergraduate education!