# The Scientific METHOD

**An astronomer describes her role in developing a course designed to instill in students the 'habits of mind' they need to better understand the world.**

BY ROBIN MCGARY HERRNSTEIN

*Editor's Note: Science and curriculum are among the hottest topics on the Furman campus today. The university is conducting a thorough reassessment of its curriculum (including General Education Requirements) and also finalizing plans for a new science complex that will foster interdisciplinary exploration and collaborative research.*

*Given this state of affairs, we sought someone who could comment on such issues as the importance of scientific literacy and the value of cross-disciplinary study from a liberal arts perspective. We found Robin McGary Herrnstein '98, who holds a Ph.D. in astronomy from Harvard University. An active researcher, she has worked at a variety of sites, including the Robert C. Byrd Green Bank Telescope in West Virginia (right), which is operated by the National Radio Astronomy Observatory. For the past two years she was also deeply involved in the development of a Columbia University course geared to help students apply the basic tools of science to expand and strengthen their knowledge of the world. Her insights follow.*

ROBIN HERRNSTEIN

It is 9:20 a.m. on a Monday morning in early May. I am sitting at a desk at the front of a classroom while 80 Columbia University students (40 of whom are my own) are diligently working on their final exams. They are a diverse group, with intended majors ranging from Baltic history to mathematics and modern literature.

However, the students are not the only ones that are nervous. I have my usual final exam butterflies as well. Mostly, I wonder: Will they do well? Have they really learned something? Will they actually use it after this course? Will just a few of them look at the world a little differently from now on? In other words, I am wondering if this course and my teaching have been successful, and whether the students have learned the life skills that I have tried to teach them.

What is this course that I feel is so critical for their futures? It's called "Frontiers of Science," and the life skills that I hope they have mastered are the tools of science.

Science is universally accepted as a key element of a liberal arts education. However, the form in which science is taught varies widely among institutions. Many liberal arts schools, including Furman, have incorporated science into the curriculum by requiring students to take a certain number of science courses as a prerequisite for graduation. Students choose topics that interest them the most — and then, it is hoped, they learn the fundamental ideas in these disciplines. Another common approach in the teaching of science is to focus on the philosophy or history of a specific subject.

As a scientist, I do not find either of these approaches appropriate. Studying the philosophy of science is very different from doing science, just as studying the philosophy of writing is very different from picking up a pen and composing a novel.

Courses in the history of a science may focus on great discoveries, but they too have drawbacks. One of the defining characteristics of science is that it is constantly building on the discoveries of those who have come before. As a result, science has come a long way since the days of Galileo, Newton and even Einstein. In fact, every current Furman student probably knows more about the universe than did any of these men.

Today, for example, it is common knowledge that there are galaxies outside our own. However, this discovery wasn't made until the 1920s and was unknown even to Einstein in the early days of the 20th century. Therefore, while it is certainly necessary to understand Einstein's theory of special relativity in order to understand the physics built upon it, it is unfair to study his accomplishments without considering the progress that has been made in physics and astronomy over the last 75 to 100 years.

I like to think of these three approaches as the "facts," the "philosophy" and the "story." Together, they comprise nearly 100 percent of all liberal arts course requirements in the sciences. But are they the only ways to approach general science education at the undergraduate level?

Perhaps not.

CHARLIE REGISTER

**In** August 2003, I was hired as a post-doctoral Science Fellow in Astronomy at Columbia University.

At Columbia, I also joined a group of like-minded scientists in an experiment to see if there is a better way to approach science education at a liberal arts college. My role during the past two years was to continue and expand my research in astronomy — and to help design and teach a new course for first-year students called "Frontiers of Science."

You may be asking, "Why do we need a new approach to science education?" In answering this, we must first consider the objectives of a liberal arts education.

The primary objective of liberal arts programs is to produce well-rounded graduates who will become productive citizens. But how does science fit in to this idea? Do we simply want students to have an appreciation for science? Do they need some basic knowledge in one or more specific fields? Or is there something more that we can teach them?

It is common knowledge that American students lag behind their counterparts around the world when it comes to science and mathematics. This fact should be of concern not only to scientists, but to the country as a whole. Without basic science literacy, citizens must rely on the words of others, as opposed to formulating their own opinions. They must simply accept the scientific claims that are presented to them through the media. Such reliance on outside sources can make people susceptible to gimmicks, deception and misunderstandings.

Suppose you hear a two-minute story on the evening news announcing a possible breakthrough in treating cancer. Should you consider the new treatment? Or perhaps you read a news item announcing the discovery of a correlation between some environmental factor — let's say a favorite baseball team — and a child's ability to succeed in school. Should you automatically encourage your daughter to drop the Braves and become a Red Sox fan?

To answer these questions, you need the basic tools of science. You need to know how to examine and interpret data. Is the result significant? Did they test the new cancer drug on enough people? What other factors might be causing the observed correlation between supporting certain baseball teams and grades in school?

These are questions that all of us *should* ask. Most scientists ask them almost as second nature; we are, after all, a skeptical group. It's not that we believe everyone else is doing shoddy research. Instead, as scientists, it is our job to question, to check and, ultimately, to discover for ourselves if the data are convincing.

**The** desire to instill in students the critical thinking skills and quantitative tools that scientists use to look at the world led the science faculty at Columbia to develop "Frontiers of Science" as a new core course for first-year students. Rather than focusing on facts or stories, this course focuses on the skills used by scientists to advance our knowledge of the world around us.

KATIE LEVANS

Termed the "Scientific Habits of Mind," these skills include graph reading, estimation techniques, basic statistics, correlation and causation, proxies, models and data analysis. Students learn these skills by studying current research in four "hot" fields, such as conservation biology, brain and vision, global climate change, and the evolution of language. Once they complete the course, the theory goes, they should be able to apply the skills they learn to their lives.

Not only does the design of "Frontiers" prepare students to approach the world in a more quantitative manner, but it also gives them an accurate picture of what science and scientists are really like.

For one thing, the idea that unexplained scientific mysteries still exist is often lost in introductory science courses. While focusing on current "frontiers," students become involved in the debates and questions that occupy the research time of their instructors. Early in the term, students often can't understand why their instructors don't know all the answers. It takes time for them to accept that some questions simply haven't been answered yet! However, once they develop an appreciation for this idea, I believe they find science more exciting.

**One** of the most unique characteristics of "Frontiers" is that each professor teaches every subject. Over the past two years I taught stellar astronomy, environmental biology, global climate change, the anatomy and physiology of the brain and its relation to vision and language, the fundamental networks of the human body, and more. While this can be disconcerting at first (to both instructor and students), the idea is that as a Ph.D. scientist you have mastered the "Habits of Mind" and can apply them to fields outside your expertise.

Most students respond positively to this approach, and many say that they learn a lot by watching the way I approach a new scientific idea or question. What questions do I ask? What do I believe? What makes me skeptical? In some ways, my own lack of expertise may be the most efficient way to convey the elements of scientific thinking to undergraduate students.

One other feature of "Frontiers" makes it an unusual course. As a result of the structure of the core program at Columbia, all first-year students — even the roughly one-third who plan to major in mathematics or science — take "Frontiers of Science" (along with eight other core courses). While this approach differs from Furman's, which allows students to select from an assortment of General Education courses, it raises an interesting question: Can a core science course offer anything of value to science majors?

I believe it can. One of the main goals of a liberal arts college is to produce well-rounded graduates. As did all of my Furman classmates from the mid-1990s, I found myself taking a wide variety of classes as an undergraduate: French, religions of the world, modern Japanese history, and others. However, the one area in which I was not especially well-rounded was science.

As a physics major, I fulfilled my General Education science requirement with classes in my major. As a result, I did not take a single class in biology, geology or even chemistry while at Furman. In graduate school, I became even more specialized. I focused on astronomy, then radio astronomy, then radio emission from the center of the Milky Way galaxy, until I eventually defended a thesis on the molecular environment around the supermassive black hole at the Galactic Center.

My story is not unique. Scientific fields, and the scientists who work in them, are becoming increasingly specialized. This specialization is necessary because of the vast amount of knowledge and rapid pace of discoveries in each field.

But does specialization mean that a geologist must completely lose touch with current research in astronomy, chemistry or biology? And, if so, is the abandonment of all other sciences really in the best interest of a geologist, or of geology in general?

Since becoming involved in "Frontiers," I have learned (and taught!) evolutionary biology, Earth-climate, the evolution of language in humans, and the chemical processes that regulate the networks in our brains and our cells. These interdisciplinary opportunities have been among the most rewarding aspects of my job. I have renewed my general interest in *all* science — and some fields that never interested me before, such as biology and geology, now seem to be the most exciting.

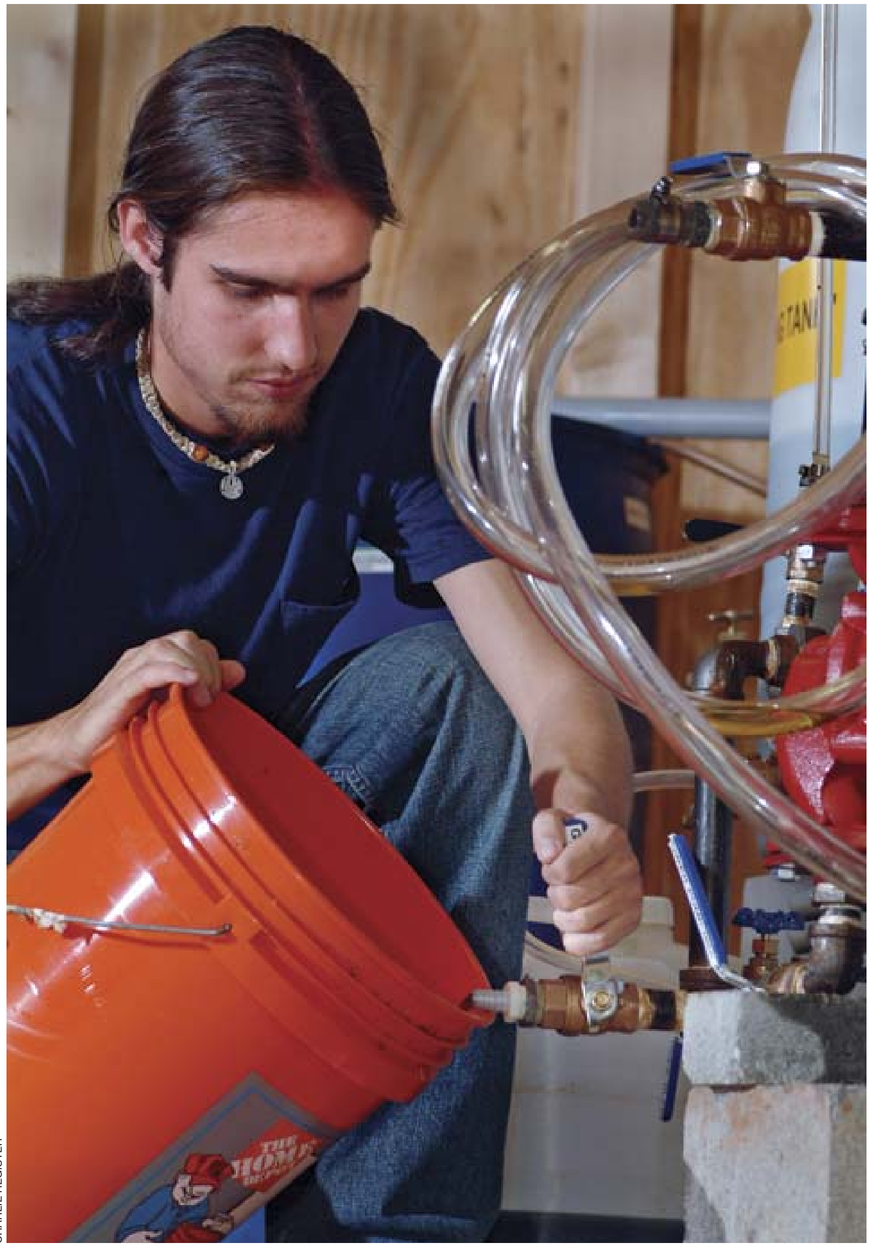
The cross-disciplinary structure of "Frontiers" also encourages interaction among the scientists involved in the course. In the past two years, I have worked with scientists from fields outside physics and astronomy whom I almost certainly would not have met otherwise. The toughest questions I have been asked about astronomy have come from biologists and geologists. This interaction has caused me to look at my field and my research in a new light — and to remember the importance of keeping the big picture in mind while conducting my own research.

I believe undergraduate science majors also benefit from a cross-disciplinary experience if it is carefully designed so as not to be a general survey course. In "Frontiers," we do *not* try to cover all of science. Rather, we focus on a few hot topics. The research we study is cutting-edge; few (if any) students examined these topics in high school. In fact, we often use articles from recent issues of *Nature*, or even unpublished work by our colleagues. This "frontier" approach produces science majors with an understanding of important current questions and challenges in fields other than their own.

The course's structure also offers students interested in the sciences a unique opportunity to see current research in several different fields before beginning their own major. The focus on research gives them a sense of what it is like to actually *be* a professional biologist, geologist or astronomer. What is it like to work in a lab, to do field work in East Africa, to analyze data from the Hubble Space Telescope?

Students are invariably amazed to discover that the majority of my research time as an astronomer is spent in my office in front of a computer rather than on a distant mountaintop. In fact, I spend only a tiny fraction of time gathering data (and even this can often be done remotely, with the data being sent to my computer via e-mail). The analysis and interpretation of the data take the majority of my time.

With a better knowledge of the process of research in a variety of fields, first-year science majors can make a more informed decision when they choose the field in which they want to major. I have seen more than one student change his or her intended science major as a result of this course. Who knows . . . if *I* had taken "Frontiers," perhaps I would now be writing this article as a climatologist or behavioral psychologist!


CHARLIE REGISTER

**The** "Frontiers" approach is far from complete. Although we have learned a lot about science education in the past two years, there is ample room for improvement. The course is certain to evolve over the next few years, as we continue to seek the best way to get our ideas across to students.

Regardless of the final outcome for "Frontiers," I think there is a growing feeling at many universities (including Furman) that the science component of liberal arts requirements should be carefully considered and modified to reflect the changing needs of students. It has been rewarding to be a part of the development and implementation of one college's attempt at a new approach to science education.

While the implementation of such a course must be tailored to each university, the ideas and goals of a skill-based science course can be applied in a variety of university settings, and even in high schools. Ultimately, I believe that students who emerge from college equipped with the quantitative tools and critical thinking skills associated with science will have a great advantage in the increasingly complex and changing world in which we live.

*The author graduated* summa cum laude, *Phi Beta Kappa from Furman with degrees in mathematics and physics. While doing her graduate work she was a Harvard Merit Fellow and recipient of the Harvard Teaching Award. To learn more about her work, visit her Web site at http://www.astro.columbia.edu/~herrnstein.*

## In Townes' footsteps

**When** working in astrophotography as a freshman at Furman, I never thought that I was taking my first steps toward becoming an astronomer. And when, as a graduate student at Harvard, I decided to study molecular emissions from the center of the Milky Way Galaxy, little did I know that I was following in the footsteps of Charles Townes — arguably Furman's most illustrious graduate.

Townes is best known for his groundbreaking work in the development of the maser and laser, which earned him the Nobel Prize in physics in 1964. However, few people are aware of his work in astronomy.

Although I knew about Dr. Townes as an undergraduate — after all, most of the prize lectures occurred in Plyler Hall's Townes Auditorium — I did not appreciate his contributions to astronomy until I was in graduate school. When I chose to work with Dr. Paul Ho of the Harvard-Smithsonian Center for Astrophysics, the first paper he had me read was titled "Interstellar Ammonia" — by Ho and Townes. The paper covered the physics of emission from molecules of ammonia that are found in dense clouds of gas where stars are formed. I would be looking at emission from these molecules as part of my thesis.

The connections didn't end there. Not only did I observe molecular emission at microwave wavelengths from ammonia molecules; I used this emission to study the structure and kinematics of gas clouds near the supermassive black hole at the Milky Way's Galactic Center. It turned out that the Galactic Center was one of Townes' specialties, and I came across his name many times as I was doing my research.

In March of this year, I attended a conference on the Galactic Center held at the University of California-Santa Barbara, where I was scheduled to give the opening talk. As I ate a bagel and set up my laptop, I looked into the audience. There was Charles Townes! We had met a few times before, but I had never presented my research to him. Fortunately he received my work favorably, although not without asking some penetrating questions (as he did on a number of occasions throughout the conference).

After my talk we were discussing our common backgrounds, and he pointed out that he, too, had spent time at Columbia early in his career. In fact, it was during his stint at Columbia that he developed the maser, using ammonia gas. Once again, I had unknowingly followed in his footsteps.

I have always enjoyed sharing a Furman connection with Dr. Townes. His continued support of science at Furman — including his generous gift for the new science complex — is a true testament to the fondness with which he views his alma mater. I hope that, in this regard, I will once again follow his lead and be able to give something back to Furman in the future.

**— Robin McGary Herrnstein '98**


COURTESY ROBIN HERRNSTEIN

*The author visits Atacama Desert in Chile, site of the Atacama Large Millimeter Array telescope.*