

impair their function. The engineered virus was still able to invade bacteria and replicate, according to Endy. “We’ve demonstrated it’s possible to redesign a genome” beyond adding individual genes, he says. Now, he and his colleagues are adding more bases to the T7 genome, testing the limits of this expansion technique.

Making genomes bigger or smaller is just a tiny step in realizing the true potential of synthetic biology. The field needs to move forward on many fronts, says Venter. Synthesizing new chromosomes from scratch, for example, remains a challenge. In one effort in that direction, Smith and his colleagues have for the past few years been knocking out individual genes in *Mycoplasma genitalium*, which has the smallest known genome of a free-living organism (*Science*, 14 February 2003, p. 1006). So far, they’ve identified about 100 genes, out of nearly 500, that *M. genitalium* can live without.

Their eventual goal is to identify the microbe’s essential sequences and then see if they can synthesize and assemble just those sequences and use them to create a living organism by inserting the humanmade chromosome into a cell. Among the many details to be worked out, says Smith, is how to piece together relatively huge sections of DNA. Ideas include using live cells to put together chunks of DNA into a whole mycoplasma chromosome or putting an efficient DNA repair system—such as seen in bacteria resistant to radiation damage—into a test tube to accomplish this task. Then his team must determine how to stick this DNA into a cell and remove the native DNA, without affecting the cell’s ability to function.

Ethical and environmental concerns must also be dealt with before synthetic biology fully matures as a field. MIT, the Venter Institute, and the Center for Strategic and International Studies in Washington, D.C., have teamed up to examine issues such as how to keep any new life forms created under control. This effort is funded by a \$570,000, 15-month grant from the Alfred P. Sloan Foundation. Some researchers are already exploring strategies to incorporate safeguards. For example, Church and Endy are developing ways to keep synthetic genes from escaping and possibly wreaking havoc. One solution: Alter synthetic genetic codes such that they are incompatible with natural ones because there is a mismatch in the gene’s coding for amino acids.

A final issue confronting synthetic biology is cost. The bigger the DNA piece synthesized, the less accurate the sequence and the more expensive it is to get it right. But new technologies are rapidly coming on line, note researchers. “The cost of accurate DNA synthesis and sequencing is plummeting, and as it does, we will see a quantum shift in what people dream of and do,” says Church.

—ELIZABETH PENNISI

Education



Forging a Cosmic Connection Between Students and Science

By deploying cosmic-ray detectors at high schools, physicists hope to inspire students and score real scientific discoveries to boot

Twelfth-grader Treasure Sheppard has aspired to become an aerospace engineer since she was 7 years old. But nothing fired the bright and bubbly 17-year-old’s passion for science and technology quite like a weeklong visit to the California Institute of Technology (Caltech) in Pasadena, where she and a classmate assembled a detector to snare cosmic rays—subatomic particles zooming in from space. “I was expecting a few lectures” from Caltech physicists, says Sheppard, who attends nearby South Pasadena High School. “But when we got there, they handed us a piece of paper and said, ‘These are the instructions.’ They had confidence that we could complete the task.”

That detector is now part of the California High School Cosmic Ray Observatory (CHICOS), an array of detectors stretching across the roofs of 70 high schools and middle schools in metropolitan Los Angeles. Unlike typical high-school science projects, CHICOS aims to do cutting-edge research by probing the nature of cosmic rays. That prospect thrills Sheppard, who last year tended the two detectors on her school’s roof. “CHICOS gave me an opportunity to participate in research,” she says, “which some college students can only dream of.”

CHICOS is one of several arrays that have sprouted up across North America and Europe. Using salvaged parts, a little newfangled electronic gadgetry, and student labor, particle physicists are outfitting schools from rural Nebraska to downtown Amsterdam with simple, inexpensive cosmic ray detectors. At least six sizable arrays are up and running, and as many more are in the planning. Physicists aim to stimulate teachers and students by

bringing real science into the classroom. At the same time, they hope to grab scientific glory on the cheap by discovering phenomena that more-expensive research arrays might miss.

Cosmic rays enable educators to bring science to the students instead of busing the students to visit some distant lab, says Gregory Snow, a physicist at the University of Nebraska, Lincoln, and leader of the Cosmic Ray Observatory Project (CROP), an array with detectors at 26 schools across the state. “Cosmic rays are going through every high school in the world all the time,” he says. “That allows you to get people involved in research right where they live and go to school.” The National Science Foundation has funded several of the arrays, and the primary goal of the projects is education, says Randal Ruchti, a program officer in experimental particle physics at the foundation. Still, he says, it’s possible that “a student could participate in a revolutionary discovery.”

To fulfill both their educational and scientific missions, however, the projects must balance the students’ need to tinker with the detectors against researchers’ need to keep machinery running full-time. And there’s no science that can tell physicists how to strike the proper balance.

Finding a niche

Every second, hundreds of cosmic rays pepper every square meter of Earth. If a ray has enough energy when it crashes into the atmosphere, it produces a cascade of particles known as an “extensive air shower.” For decades, physicists have studied air showers with detectors arrayed on the ground, using the

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