CHRISTOPH WEHRER/STIFTUNG HAUS DER KLEINEN FORSCHER

INNER SCIENTISTS UNLEASHED

Educators worldwide are experimenting with new ways to teach future researchers — from preschool onwards.

BY MONYA BAKER

The five-year-olds are confident: trees, they agree, make the wind by shaking their branches. Their teacher does not correct them, but instead asks whether anyone has seen the wind in a place where there are no trees. One boy recalls a visit to the seashore, where the wind was whipping up water and sand with no trees in sight. Another child says that moving cars make fallen leaves twirl. Perhaps, they decide, trees are not the source of a breeze.

So goes a typical day for participants of Germany's *Haus der kleinen Forscher* (Little Scientists' House), a programme that in less than a decade has grown to reach about half of that country's children between ages three and six. Launched in 2006 by a group of German business leaders who were dismayed by their country's lacklustre performance on international student exams, Little Scientists' House got support and funding from the federal government in 2008. Today, versions of the programme are also operating in Australia, Austria, the Netherlands, Brazil and Thailand — including more than 14,000 centres in Thailand alone.

Little Scientists' House is just one of many programmes around the world that try to inspire young people's inner scientists through active engagement with the world around them. The effectiveness of this approach has been verified by hundreds of empirical studies. "It means learning content not as something you memorize and regurgitate, but as raw material for making connections, drawing inferences, creating new information — learning how to learn," says Jay Labov, a senior education adviser at the US National Academy of Sciences, one of many organizations to endorse this mode of learning. Here, *Nature* profiles innovative exemplars of such engagement, from preschool to university. If someone wanted to turn a toddler into a scientist for the twenty-first century, this is what the curriculum might look like.

Children at a German kindergarten have just found out how to make their 'bottled tornado' work.

PRESCHOOL EXPERIMENTERS

Little Scientists' House marks a departure from educators' traditional role, says Christina Jeuthe, a kindergarten teacher who participates in the programme. "You have to be willing to do something with the kids that might not lead to a result," she says. "They will not take something home that they can show their parents." Instead, teachers trained in the method try to get children to ask questions about natural phenomena and everyday objects. And when the children give naive answers (for example, that shaking leaves produce wind), the teachers help them to come up with activities to test those answers — in effect, emulating how grown-up researchers do science. But just as with scientific discovery, the end points are uncertain, says Jeuthe. "I myself had to be strong enough to not put my expectations on a specific scientific question for the kids — but let them decide, ask and discover."

In a unit about water, for example, one five-year-old argued that more water drops could collect on a euro coin than on a slightly larger 50-cent piece because the former buys more. He and his classmates counted how many drops they could dribble onto the coins' surfaces. In the end, the children could not come to a definitive answer, but that is OK, says Jeuthe. The point is to spark questions, and a conviction that they can be explored rationally.

Activities start with objects and experiences that children are familiar with — which can call for considerable creativity when adapting the programme to different places and cultures. The Australian version cannot draw on children's experience of wintry weather; instead, they focus on ice cubes. In Thailand, one activity relies on sky lanterns — miniature hot-air balloons that are common in holiday festivities. However it is done, the children say that they have fun carrying out their impromptu experiments — and in the process, say advocates of the programme, the children are learning invaluable lessons on how to plan and solve problems, not to mention gaining self-confidence.

Unfortunately, pinning down the programme's effects on students will be hard, warns Mirjam Steffensky, a chemistry educator at the Leibniz Institute for Science and Mathematics Education in Kiel, Germany. If nothing else, she says, comparisons are difficult because educators in each location are free to implement the Little Scientists' House curriculum in different ways. Still, the German Academy of Science and Engineering and other education foundations have commissioned Steffensky and several other researchers to carry out independent assessments of the programme. The three-year studies, which include control groups, will cover hundreds of students from dozens of centres to see whether the programme boosts children's language and science skills.

These assessments will not be completed until next year, but a 2013 questionnaire of more than 3,000 participating educators found that they felt more confidence and interest teaching science. "Just give the children the room, the time and the possibility," says Jeuthe. "Believe that they will work it out, and they will."

HIGH-SCHOOL COLLABORATORS

The Hwa Chong Institute (HCI) is an elite high school in Singapore that enrols only the best-performing students and then gives them access to advanced equipment, including an atomic force microscope and cell-culture incubators. The tools would be the envy of many a university, but to director of studies Har Hui Peng, that is not enough. She has always wanted to give her students an extra challenge, and a flavour of doing science in an interconnected world. She got her chance a decade ago thanks to a lucky encounter with George Wolfe, a US educator who told her that he was setting up the Academy of Sciences (AoS): a selective, publicly funded high school in Sterling, Virginia, where students could design and conduct research. Both recognized a unique opportunity to teach their students a skill essential for twenty-first-century science: collaboration.

Every October or November since 2006, a dozen or so 14- and 15-year-old HCI students have travelled to the AoS to start research projects that will last the academic year. They work in teams of four — two students from each country — on projects such as screening maggots for antimicrobial compounds. Nine months later, the AoS students join their HCI teammates back in Singapore to complete the final analysis and prepare presentations of the results.

Particularly at the beginning, some of the cultural stereotypes applied, says Ashley Ferguson, who took part in the programme as an AoS student. The US students were "more creative and free-flowing", she says, whereas their HCI teammates were more focused and directed: they considered what instruments were available and what experiments could be designed around them. "Some of that more-structured thinking was good for us to learn," says Ferguson, now a senior student at the University of Virginia in Charlottesville.

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Ernest Chen, an HCI graduate now studying at the University of Cambridge, UK, says that the project taught him the importance of communication. When he hit a snag with his project — chemically modifying a polymer to sop up dissolved metal ions — he and the other HCI student in his team wanted to change the methods. This annoyed their AoS teammates, who wanted to stick with the agreed protocol. The resulting e-mail exchanges taught everyone the skills of persistence and persuasion. "Instead of just sending a first e-mail saying, 'I'm going to change this', I would say, 'we tried this, and it doesn't work, therefore we want to change it'." Several years later, the team still stays in touch over social media.

Most important is learning to work effectively as a team, Har and Wolfe agree. The best part is when the students "start to care for each other", says Har. For example, students at one school will make sure their part of a project is completed well before another schools' exams to give their colleagues time to study, she says.

Such consideration is exactly the point, says Wolfe, now director of the AoS. "Our mission is to teach kids to do science. If you look at what scientists really do in the real world, people don't work in a vacuum."

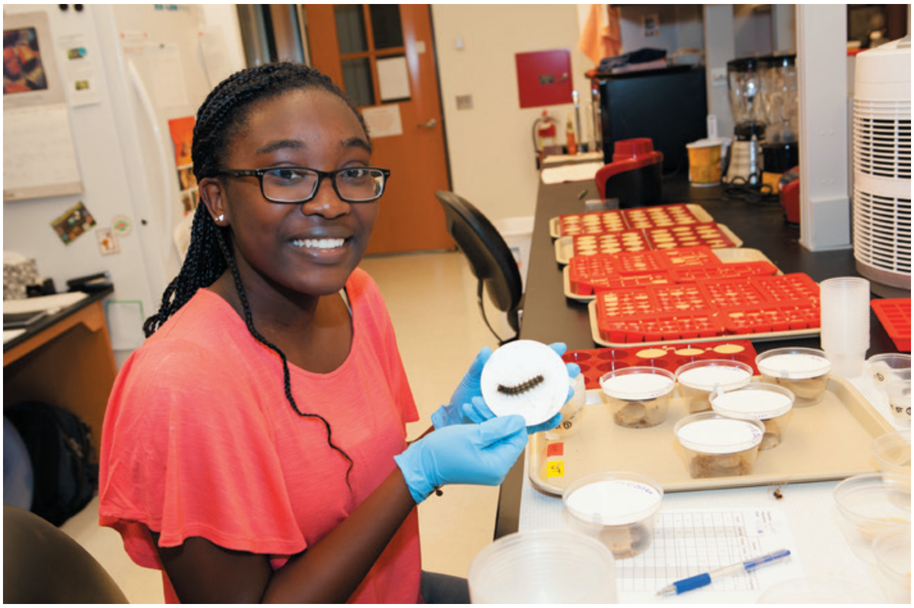
TEENAGE RESEARCHERS

Cal Hewitt does his physics calculations by accessing a grid of distributed computers set up in the United Kingdom by CERN, the European particle-physics lab near Geneva, Switzerland. Tapping into the equivalent of nearly 40,000 personal computers, Hewitt and his colleagues are calculating the types, energies and trajectories of particles detected by an experiment developed at his institution and launched into space last year. The group's findings could suggest ways to prevent damage to satellites, and perhaps firm up theories about the source of extragalactic cosmic rays. And with any luck, this will happen before Hewitt turns 18.

Hewitt is a student at the Simon Langton school in Canterbury, UK, where students routinely design and perform real, ambitious experiments. Some of the students — Hewitt included — have presented their work at scientific conferences; a few have even published original research in the peer-reviewed literature.

The school's philosophy is simple, says Becky Parker, who directs the Langton Star Centre, which hosts the school's research programmes: "Let's give students a chance to do real science and get the thrill of discovery."

Simon Langton is a state-funded, elite institution: students are accepted on the basis of an aptitude test at the age of 11. But the school's path to teen research began just over a decade ago, when Parker decided to sign up for a programme that gave secondary students remote access to telescopes in Australia and Hawaii. Rather than opting for the standard teacher-led



UNIV. RICHMOND

Summer lab research for a student on the University of Richmond integrated science course.

demonstration, Parker handed the reins to her students — who used their freedom to confirm the presence of half-a-dozen known asteroids with orbits that bring them near Earth, and went on to discover two new ones.

Around the same time, Langton students entered a competition run by the UK National Space Centre to design an experiment that would be conducted in space, basing their proposal on cosmic-ray-detection technology that they had encountered on a field trip to CERN. Contest organizers offered to launch the programme if students found the funding for it. They did. And high-calibre research projects have topped students' extracurricular activities ever since.

Now the students are running calculations on data from CERN's MoEDAL (Monopole and Exotics Detector at the Large Hadron Collider) to look for some of physics' most exotic phenomena, such as microscopic black holes. Langton is the only secondary school participating as a full member in any major particle-physics collaboration, says James Pinfold, a particle physicist at the University of Alberta in Edmonton, Canada, and spokesperson for the MoEDAL collaboration. "This work in space convinced us they could handle the job," he says.

Elsewhere in the school, one student team is using genetic analysis to breed and evaluate drought-resistant strains of wheat. Another is unravelling molecular mechanisms for multiple sclerosis — a project that required a licence for genetic modification of yeast so that the students could investigate the human gene for myelin basic protein. Langton is the first secondary school to get such a licence.

Parker estimates that Langton supplies almost 1% of all students, and at least 2% of female students, who enter undergraduate physics programmes in the United Kingdom.

Other secondary schools also promote student-led research. But the scale, scope and quality of the work at the Langton centre make it stand out. To support the work, Parker and her students have raised funds from bodies such as local government and national science organizations. Such awards even supported a particle physicist to work on Langton's campus full time to advise students and build research capacity at other secondary schools.

Most credit Parker for the school's scientific success. (At one point, project teams were limited to the number of students she could fit in her car.) But Parker says that teachers are eager to put in the time for extracurricular research once they see what is possible.

To help the Langton idea spread, Parker's next project will be the Institute for Research in Schools, which will support school science teachers who want to launch genuine research projects.

And that is what education should be, says Caitlin Cooke, a Langton student who works on the MoEDAL team. "Because we've already experienced so much work at the frontier, it demonstrates to us the reality of what it is to do physics." Her colleague, Fleur Pomeroy, agrees. "Why do people question why we can be doing real science?"

INTERDISCIPLINARY UNDERGRADUATES

When Tyler Heist was considering his first year at university, he decided to throw himself into science with abandon. Most university science courses are run by individual departments and focus on a single discipline. But the Integrated Quantitative Science class at the University of Richmond in Virginia offered simultaneous introductions to five: biology, chemistry, physics, mathematics and computer science. Better still, the course would organize the lessons around interdisciplinary problems such as antibiotic resistance and cells' responses to heat. In 2010, Heist applied for one of the course's 20 available spots and was accepted. Inspired by that experience, he will head off later this year to do doctoral work in computational biology at Princeton University in New Jersey.

The origins of the integrated course stem from a report issued more than a decade ago. The US National Research Council concluded that biological research had changed dramatically to incorporate physical and computational sciences, but biological education had not. April Hill, a biology professor at the University of Richmond, thought that the best way to fix that problem was to retool the introductory courses to view core concepts from many disciplines through the lens of real science questions, rather than taking students on the traditional march through the disciplines one by one. Hill and her colleagues ran their course for the first time in 2009.

Although interdisciplinary courses are hardly new, Hill's approach stands out for combining five distinct disciplines, for targeting introductory classes, and for including a stint of paid laboratory research in the summer following the course. Ellen Goldey, who chairs the biology department at Wofford College in Spartanburg, South Carolina, says that the University of Richmond effort has inspired other undergraduate institutions to set up similar programmes. "There is an existing model now so they will not need to reinvent the whole wheel," she says.

Hill says that the extra effort required to integrate multiple disciplines more than pays for itself; the course has prompted cross-disciplinary collaborations in her own work, on gene networks that govern the development of the most basic multicellular creatures. "Now that I have six years of interdisciplinary teaching I can't imagine not doing it," says Hill.

In 2012, the number of students taking interdisciplinary courses doubled at the university, as did efforts to recruit students from a minority background. A companion programme called SMART, now in its second year, serves students with less rigorous high-school preparation. A precollege summer programme full of mentoring and maths helps to prepare students for the interdisciplinary courses. More than 30% of the students who took the integrated class in 2009 and 2010 went on to PhD programmes. Those who take the integrated course are more likely to graduate with a STEM major — 92% versus 60% or less of other undergraduates who start out in STEM. And they also take a greater variety of classes.

Heist, for example, says that the programme helped him to get through upper-level classes that required him to read primary biology literature that incorporated concepts from physics or computer science, and credits the course with broadening his approach to scientific investigation. "It makes you rethink the boundaries you put on things," he says. ■

Monya Baker *writes and edits for* Nature *in San Francisco, California.*