Big plans for little brains

Experts in neuroscience, computing and education are coming together in a massive effort to put the way in which children are taught on a sounder scientific footing. **Trisha Gura** profiles this ambitious — some might say foolhardy — initiative.

In 1997, John Bruer, the president of the James S. McDonnell Foundation, launched a broadside against the fashion of taking findings from neuroscience and trying to apply them in the classroom. Experienced in both cognitive science and education, Bruer set out to demolish the hype surrounding what he saw as blatant pseudoscience.

"Currently, we do not know enough about brain development and neural function to link that understanding directly, in any meaningful, defensible way, to instruction and educational practice," he wrote, arguing that so-called brain-based curricula had crossed "a bridge too far"[1].

Now, however, the US National Science Foundation (NSF) has decided that it's time to span the great divide between neuroscience and education. Over the next five years, it is giving more than US$90 million to four large, multidisciplinary teams incorporating cognitive neuroscientists, psychologists, computer scientists and educationalists. A further series of grants will be announced later this year.

Rather than making the simplistic connections that so irked Bruer, these teams want to give the craft of teaching a solid scientific underpinning. They aim to devise practical teaching methods that will complement the brain's natural development, in part by integrating advances in cognitive neuroscience with cutting-edge information technology.

"The science of learning is ripe for a breakthrough," claims Andrew Meltzoff, co-director of the Institute for Learning and Brain Sciences at the University of Washington in Seattle, which is leading one of the four NSF-funded teams. "And the way it will occur is to build a bunch of 'mini bridges' from one discipline to another, instead of one big unsupportable bridge that goes all the way from neuroscience to education."

Treacherous territory

Maybe so, but Meltzoff and his colleagues are stepping into treacherous territory. Education is a highly politicized field, experts warn, littered with obstacles to reform and populated by powerful individuals with their own pet theories. "Even with good ideas, getting them into the classroom requires you to jump over all these political hurdles, some of which you have no control over," cautions Pamela Clute, a specialist in mathematics education at the University of California at Riverside, who spends much of her time working with elementary and high-school teachers.

Until now, science and educational research have not mixed well. Lacking common measurement standards, educationalists have touted theories that are more like philosophies, says David Klahr, a psychologist at Carnegie Mellon University in Pittsburgh and a member of another of the NSF-funded teams. "In education it's like: 'Here's my theory. I think kids can do this or can't do that,'" he complains. "So theory is very mushy."

As a result, the field evolved into camps of specialists fighting to advance one theory of learning over another. Meanwhile, neuroscientists were holed up in their labs testing the ability of new imaging tools to deliver clues about which areas of the brain are involved in key aspects of learning. In another intellectual ghetto, computer scientists were busy using neural networks and fancy algorithms to model learning. Pity the poor teachers who were left trying to make sense of it all, barraged with brain-based pseudo-theories with no credible basis.

The challenge was to get everyone working together. So two years ago, the NSF asked researchers to come up with proposals to address fundamental aspects of learning, each of sufficient size and scope to warrant a grant of more than US$20 million. Each proposal also had to reach directly into the classroom or another real-world setting.

Now the first four teams to be selected are getting down to work. At Dartmouth College in Hanover, New Hampshire, neuroscientists are using magnetic resonance imaging (MRI) to visualize the activity of children's brains as they learn. A collaboration led by the University of Washington is investigating how the brain learns in a variety of settings. At Carnegie Mellon University, meanwhile, computer scientists and psychologists are leading a team that is refining computer-aided teaching tools. They are also setting up a 'LearnLab' in which teachers can get involved in the group's research. And a team headed by researchers at Boston University is creating textbooks and modules that focus on the mind and how it learns — with the goal of training teachers, as well as students.

> "We are peeking under the hood at something that underlies the ability to read."
> — Michael Gazzaniga

The Dartmouth team has the strongest neuroscience component. Team leader Michael Gazzaniga is using a technique called diffusion tensor imaging, which analyses MRI data to determine how efficiently different parts of the brain are wired together[2]. He is investigating differences between children who are fast or slow readers and, in unpublished work, has already found that connections between the two halves of the brain are much more direct in children who integrate visual information quickly — a skill that might correlate with better reading.

"We are peeking under the hood at something that underlies this ability to read," Gazzaniga says. By working out the differences in brain organization that underpin children's reading abilities, he hopes it will eventually be possible to determine which teaching methods promote the formation of the most efficient neural connections.

Also at Dartmouth, Daniel Ansari is investigating numeracy. Ansari (pictured, left) suspects that young children have two systems for doing mathematics. One system, called magnitude representation, is the crude ability to estimate quantity. Children younger than two years can usually distinguish between a large pile of candy and a small one, for instance. Ansari is testing toddlers with cards showing dots and pictures, to see if those who have trouble judging magnitude might be the ones who, later in life, will struggle with counting, addition and, ultimately, higher mathematics.

The other system, called exact number representation, involves taking the idea of a large pile versus a small pile and coming up with numbers to stand for pile size. The ability to do this marks a huge leap in cognition, says Ansari, who is trying to visualize what this development looks like in the brain. Very young children won't lie still in MRI scanners, and so can only be studied using behavioural tests. But Ansari is running MRI scans on children aged seven to twelve, and hopes to distinguish how and when a child's exact number sense begins and whether early failures to develop the skill mark those who will subsequently struggle with mathematics.

Once Ansari has figured out the brain regions involved in learning to count and estimate numbers, he can start devising exercises to facilitate the process that could one day be adopted in preschool. Older children who are having trouble with mathematics, meanwhile, might be given tests to see whether their problems lie with their sense of exact numbers, and potentially be set similar exercises to bring this basic skill up to scratch.

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Adolescent emotions

After children have entered adolescence, emotions become a major influence on their ability to perform at school. This is being investigated by Abigail Baird, another member of the Dartmouth team. She is using MRI to watch what happens in the brain when a student hears a nasty comment or a gender slur and then proceeds to flub an exam. Outreach to teens who are struggling with their emotions is central to this work: Baird and her undergraduate assistant Jane Viner have created a 10-week mentoring programme that helps teenage girls cope with aggressive interactions. Girls who took part subsequently showed an increase in the activation of their prefrontal cortex — an area of the brain thought to help rein in our emotions — suggesting that they had indeed acquired some new cognitive strategies.

In addition, the entire Dartmouth group is connecting its work with real-world education through a link with Steve Michlovitz, director of curriculum at the Windsor Central Supervisory Union, which oversees schools in Woodstock, Vermont. Formerly a school teacher, Michlovitz became interested in brain research while teaching a graduate course for education students at a local college, and more than a decade ago asked if he could bring his classes to Dartmouth to observe neuroscientists in action. Michlovitz now educates teachers about how the brain develops and functions, encouraging them to be more critical about reports on the latest findings and to

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Number crunch: toddlers who have trouble judging quantities may go on to flunk maths at school.

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Winning formula: pupils who use cognitive tutor software, which adapts to individual needs, learn algebra faster than those receiving ordinary tuition.

avoid the sort of pseudoscience criticized by Bruer. Every two years he organizes an educational conference that brings together parents, teachers, administrators and cognitive scientists from Dartmouth and elsewhere.

Outreach is also central to the plans of the Pittsburgh Science of Learning Center, based at Carnegie Mellon, where artificial intelligence researchers are building on their success in developing an automated 'cognitive tutor' for algebra. After dissecting the steps to learning algebra, a team led by Ken Koedinger devised algorithms that play the role of a tutor, doing set problems along with a student and offering hints. By scoring the student's answers, the cognitive tutor recognizes when to stop giving so many hints, and eventually withdraws completely — until the student makes a mistake or asks for help.

Pupils who use the tutor learn algebra 50% faster than those taking regular classes, and also score 10–25% higher on standardized tests[3]. Today, the tool is being used at 1,800 schools across the United States.

With the new NSF funding, Koedinger and his colleagues are teaming up with experts in other subject areas to build six more cognitive tutors in subjects including geometry, chemistry and foreign languages. They also want to have their tutors make smarter decisions about when to step back and let students try problems on their own.

But the most ambitious part of the Pittsburgh project is the LearnLab, an experiment in outreach that allows teachers and students to work with the cognitive tutors, which will tailor themselves to complement the methods employed by each teacher. Teachers are also being encouraged to get involved with learning experiments, providing a framework to conduct a wide range of educational research projects without having to build relationships with each school from scratch. "When a researcher has a great idea and they want to go do it in a school, they currently have to start out cold and get permission," Klahr says.

Even with such outreach, implementing the findings of the NSF programme will be daunting. The hurdles include cost and entrenched curriculum standards. In California, for example, a recently passed law forces districts that adopt certain textbooks to teach from them — with no deviation — in order to receive federal dollars. "Those who do education research need to go out in the real world and really see what it is going to take to implement their ideas," says Clute.

> "Education researchers need to go out into the real world and see what it will take to implement their ideas." — Pamela Clute

And then there are the teachers. In order for innovation in teaching to catch on, they have to grasp the ideas involved. Clute points out that, in California, more than half of middle and high-school teachers have no undergraduate training in the subject they are teaching. So how can reformers ever expect to succeed?

One NSF centre, based at Boston University, is tackling this problem. By creating textbooks and teaching modules that focus on learning and the mind, researchers hope not only to educate students about cognitive science, but also to open teachers' eyes to the potential of findings emerging from the NSF programme. "People have a deep hunger to understand themselves better in such a complicated technologically driven world," says Stephen Grossberg, who heads the Boston centre.

The final collaboration, between the University of Washington and Stanford University in California, is taking the science of learning out of the classroom. Meltzoff plans to team up with ethnographers — who study people in their own cultural contexts. They will visit families and hang out in playgrounds to discover how children learn outside school.

He is particularly interested in the development of rational thinking, which can be studied by looking at whether children recognize that weighing up lists of pros and cons is a better way of making a decision than flipping a coin. By the age of eight, children usually say that coin-flipping is inferior, but will often revise their opinion if told a story in which flipping a coin led to a good result. Meltzoff suspects that conversations at home have a strong influence on the development of rational thinking, and will use the new NSF funding to put this idea to the test.

Explosion of findings

While individual projects such as Meltzoff's may seem arcane in their approach, he believes that the NSF programme in its totality could transform educational research. "There is a groundswell here about trying to understand the science of learning, bringing together practice and science," he says. "We are going to see an explosion of interdisciplinary findings that we have not had before in learning science."

Bruer, once the arch-sceptic, agrees that real collaboration across the various disciplines represented in the NSF initiative could lead to advances. He even chairs the group that oversees the University of Washington team. But he still cautions against over-enthusiasm, especially given the seductive power of new brain-imaging technologies. "You never can tell where research is going to lead," he says. "But the danger to everyone, the NSF in particular, is expecting too much, too soon." ■

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