TRAINING

Building better science teachers

The latest training techniques emphasize classroom practice and design thinking.

SÉBASTIEN THIBAULT

BY JOSHUA HATCH

If you spend time with a young child it soon becomes clear that the astronomer Carl Sagan was right when he said: "Every kid starts out as a natural-born scientist…". Spend time with a typical high-school student and it's clear that the second part of Sagan's quote is also correct: "...then we beat it out of them. A few trickle through the system with their wonder and enthusiasm for science intact."

Attempts to change that dynamic are increasingly focused on teachers, particularly the way they are trained and how they interact with students. In the United States, the Next Generation Science Standards, developed by the National Research Council, outline ways for teachers to encourage student enquiry, feed their curiosity, and deepen their understanding of scientific concepts. Meanwhile, the latest teacher-training techniques place a greater emphasis on pedagogy and classroom practice as another way to improve science, technology, engineering and mathematics (STEM) education. Both approaches are seen as models for other countries that seek to improve their own STEM education.

Existing teaching methods have long been based on "the rhetoric of well-established conclusions", according to Jonathan Osborne, professor of science education at Stanford University in California. "The dominant paradigm that most teachers work with," Osborne says, "is essentially: 'I know and you don't know, and I'm here to communicate it to you and explain it to you.' And the problem with that is we know it doesn't work very well."

Not only does that approach turn off students but it may also be failing society. A 2013 report[1] from the US National Science and Technology Council stated that "current educational pathways are not leading to a sufficiently large and well-trained STEM workforce." The report further blamed the educational system for failing to produce a STEM-literate public. As a result, up to half of those who want to pursue a STEM education in college are ill-prepared by their secondary schools, according to a report[2] by the educational-testing organization ACT. Yet the demand for STEM graduates remains high. The European Commission set a goal in 2011 of adding 1 million science researchers by 2020, and in 2012 then-President Barack Obama set a target of 1 million new STEM graduates by 2025. In response, many secondary schools have been increasing their maths and science requirements.

The number of high-school students enrolled in maths and science courses rose by more than 60% in the 20 years from the mid-1980s in the

United States, according to a study[3] from the University of Pennsylvania in Philadelphia. But rises do not directly improve STEM education — they just add more pressure to the system.

Improving outcomes, says Peter McLaren, executive director of the non-profit initiative Next Gen Education, will require a shift in the classroom from a teacher-centred approach to one that helps students work through concepts themselves. McLaren, who helped to write the Next Generation Science Standards, used to teach general science in East Greenwich, Rhode Island, and recalls a lesson he once taught on gases. He had borrowed his ex-wife's perfume bottle and sprayed it around the front of the classroom. "I asked the students to raise their hands when they could smell something," he recounts. The kids were engaged and excited, and then McLaren proceeded to explain what was happening to the gas molecules. The kids' enthusiasm was quickly snuffed out by his 'let me explain' lecture.

What he should have done, he now knows, is ask his students: "What would cause the scent of the perfume to reach all the way to the back of the classroom?", and start a discussion. Asking that question would empower the students to use their knowledge and imagination to develop scientific ideas about the concept being discussed. Instead of 'learning about'," McLaren says, "it's about 'figuring it out'."

WOODROW WILSON ACADEMY OF TEACHING AND LEARNING

Woodrow Wilson Academy design fellows prepare a hands-on science lesson for local students.

BETTER BY DESIGN

Development of the Next Generation Science Standards has been a multi-year, state-led effort, based in part on standards in ten countries including the United Kingdom, Finland and Japan. At the same time, some of those same countries are looking to the United States as a model for how STEM education can be improved. Merredith Portsmore, director of the Center for Engineering Education and Outreach at Tufts University in Massachusetts, says that educators from around the world have enquired about the US approach.

"They are starting to see some of the same issues, with students not finding STEM appealing because it's not creative," Portsmore says. The educators see integrated learning — like that outlined in the Next Generation Science Standards — as a way to create more innovative and creative scientists and engineers.

However, some of the concepts might not translate easily. Some systems are built around strict standards or large class sizes that would make it difficult for teachers to give students the focused, personalized guidance they need.

The Next Generation Science Standards are supported by large organizations such as the National Research Council, the National Science Teachers Association, and the American Association for the Advancement of Science, but smaller entities are also trying to change the way science is taught in the classroom.

The Woodrow Wilson National Fellowship Foundation in Princeton, New Jersey, was founded in 1945 to address a shortage of college faculty following the Second World War. Since 2008 it has been collaborating with US universities to revamp teacher education. Deborah Sachs, director of the University of Indianapolis' Teach (STEM)[3] programme, says that in one such partnership the fellowship worked with the University of Indianapolis in Indiana to answer the basic question: "What is it that effective STEM teachers need to know in order to be successful?" The idea was to rethink how teachers were trained from the ground up.

One realization was that trying to explain concepts and then have students apply them — or worse, simply regurgitate them — did not work. Instead, teachers should create projects in which concepts become apparent as students work through real-world challenges.

Sachs cites an example in which a geometry teacher working on a lesson about circle circumference and diameter had students map phone towers and their signal strengths. As students worked through the project, they saw for themselves where there were gaps in mobile-phone coverage and developed a deep understanding of the mathematical concepts.

Since its start in Indiana, the foundation has expanded its teaching programme to 5 other states, including 31 universities. But now the foundation is starting its own teacher-training academy using one of the technology industry's favourite buzz phrases: design thinking.

The term 'design thinking' originated in the 1960s with the idea that design should be rational and solve problems, rather than simply focusing on aesthetics. It involves solving problems through research, empathy, ideation and prototyping, and was famously used in the 1980s to create Apple's first computer mouse. In that instance, the goal was not to design a snazzy new pointing device, but to give non-technical people the ability to easily use a computer. Since then, design thinking has been used to create thick-handled toothbrushes for children — it is easier for their small hands to grip a big handle than a small one — and to launch disruptive companies such as Airbnb.

MAKING A CONNECTION

Located in a small office just a 15-minute walk from the Massachusetts Institute of Technology in Cambridge, the Woodrow Wilson Academy of Teaching and Learning is home to a handful of staff and incoming students. They are busily identifying some of the problems with current STEM teacher training and are working on ways to overcome them. One challenge is to give teachers more practice managing classrooms, working with colleagues and even dealing with parents.

The staff and students came up with several ideas to address this problem. One idea was to send student teachers to Boston's Museum of Science after-school clubhouse, where they work with kids on various projects including 3D printing, video editing and website development. The students do not have to be there, so teachers need to connect with them and keep them engaged if they want the students to stick around.

Doyung Lee helped to set up the academy's curriculum in 2017 as a design fellow and will attend as a student in autumn. He says that volunteering at the clubhouse taught him how to create a welcoming and safe environment, partly by being curious about his students' entire lives. "You can be great with content knowledge or pedagogy," says Dan Coleman, the academy's chief learning and design officer, "but if you can't connect with students, you're going to fail."

Lee's experience at the science museum also

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Science teachers benefit from practising experiments before performing them with students.

taught him how classrooms can suppress a student's enthusiasm, rather than tap into it. He recalls a middle-school student who came to the clubhouse and loved video editing and animation. The student was eager to expand his skills and wanted to share what he was learning, but he was struggling at school.

This is exactly the sort of situation that the Next Generation Science Standards seek to address, says McLaren. "When kids go to an informal education opportunity," he says, such as the science museum's clubhouse, they get to pursue their interests and that excites them. But that's not what typically happens at school. "In the classroom, we say, 'that's very nice, but we're doing something else today'," says McLaren, and that squashes their eagerness. It would be better, he adds, to connect a lesson to existing student interests and then guide them within the constraints of the curriculum.

Imagine a student with an interest in video production taking a class on environmental science. By asking the student to make a video documenting an environmental-science process, such as the water cycle, the student's excitement for making the video carries over to the scientific enquiry. "If you give that kind of freedom to students," McLaren says, that's when the magic happens.

PRACTICE MAKES PERFECT

Another idea being tried at the academy is to have students practise real-world situations through a computer simulator. For example, teachers often have to deal with upset parents but rarely get to practise that encounter before it happens in real life. The simulator lets the student teacher try out different strategies and find out what works and what doesn't. "People come through the experience sweating," Coleman says. "It feels like a real encounter."

Gaining such experience as student teachers is critical because a lack of classroom experience is inversely related to teacher effectiveness — and directly related to teacher turnover. "We found huge variations in how much practice in student teaching prospective teachers get," says Richard Ingersoll, a sociologist at the University of Pennsylvania's Graduate School of Education. "Something like a fifth of all new hires have never had practice. Their first day of teaching is their first day with kids. We found this was especially true for new science teachers."

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A lack of practice as a student teacher translates to a lot of science teachers leaving the profession. Although this is applicable to teachers of any discipline, "it is particularly dreadful for science teachers, because they are the group that most frequently hasn't had any student teaching," Ingersoll says.

Although the Woodrow Wilson academy has yet to graduate any students of its own — its first class of 21 future teachers began in September — more than 80% of teachers from the foundation's work with existing teaching colleges, such as the University of Indiana, have remained in the profession five years after entering. This figure is similar to the national average, according to a 2015 study[4] by the US Department of Education.

Because STEM often relies on technology and experiments, it is important to practise its use in the classroom. One of the academy's faculty members, Andrew Wild, knows this first-hand. He earned a PhD in science education from Stanford University in California before working as a science teacher in the San Francisco Bay Area. One day he went to his classroom of 42 students prepared to teach a lesson on circuits. But it didn't go according to plan. "I remember the wires going across the room," Wild recalls, "and students were tripping on wires, pulling them from the circuit boards." There weren't enough outlets and the lesson was a near disaster. Although Wild was well-versed in the subject matter, his failure to consider space challenges and to prepare for technical problems undermined the lesson.

MODEL TEACHERS

Another important point in teacher training, McLaren says, is to teach the teachers using the methods you want them to use in the classroom. This is referred to as "modelling the model" by the academy's vice-president for strategic initiatives, Deborah Hirsch. "In order to teach differently, you need to learn differently," she says.

McLaren agrees and describes an example from a professional-development workshop. "The teachers have to be put in the position where they are playing the role of the student," he says. So to convey one of the Next Generation Science Standards such as understanding causation, teachers would be presented with classroom situations and asked to identify causes and patterns. As a result, the teachers are using evidence based on their investigation to arrive at an explanation. The 'aha!' moment, he says, is when "teachers can see how a shift in their instruction makes a world of difference."

Osborne also encourages a shift in the way STEM teachers engage with their students. He advocates teaching argumentation in science as a way for students to understand scientific concepts. "The history of science is the history of vision and argument," he says, noting long-standing debates about the workings of the Solar System and the cause of disease. This is not an easy assignment for teachers, he admits: "It's a relatively complex skill."

McLaren says it takes time for teachers to learn these skills, and he was no exception. In 2001, he won the Milken Educator Award, which is given each year to exemplary early- to mid-career teachers in each state. Even so, looking back on his teaching career, and considering how the Next Generation Science Standards shift the focus away from teachers and towards students, he says: "I want to write a letter of apology."

What would he write? "I didn't give you enough opportunity to choose your path of investigation… I should have let go more and have you figure it out more." ■

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1. *Federal Science, Technology, Engineering, and Mathematics (STEM) Education: 5-Year Strategic Plan* (National Science and Technology Council, 2013).
2. *The Condition of College & Career Readiness 2016* (ACT, 2016).
3. Ingersoll, R. *Kappan Mag.* **92**(6), 37–41 (2011).
4. Gray, L. & Taie, S. *Public School Teacher Attrition and Mobility in the First Five Years* (NCES 2015-337) (US Department of Education/National Center for Education Statistics, 2015).