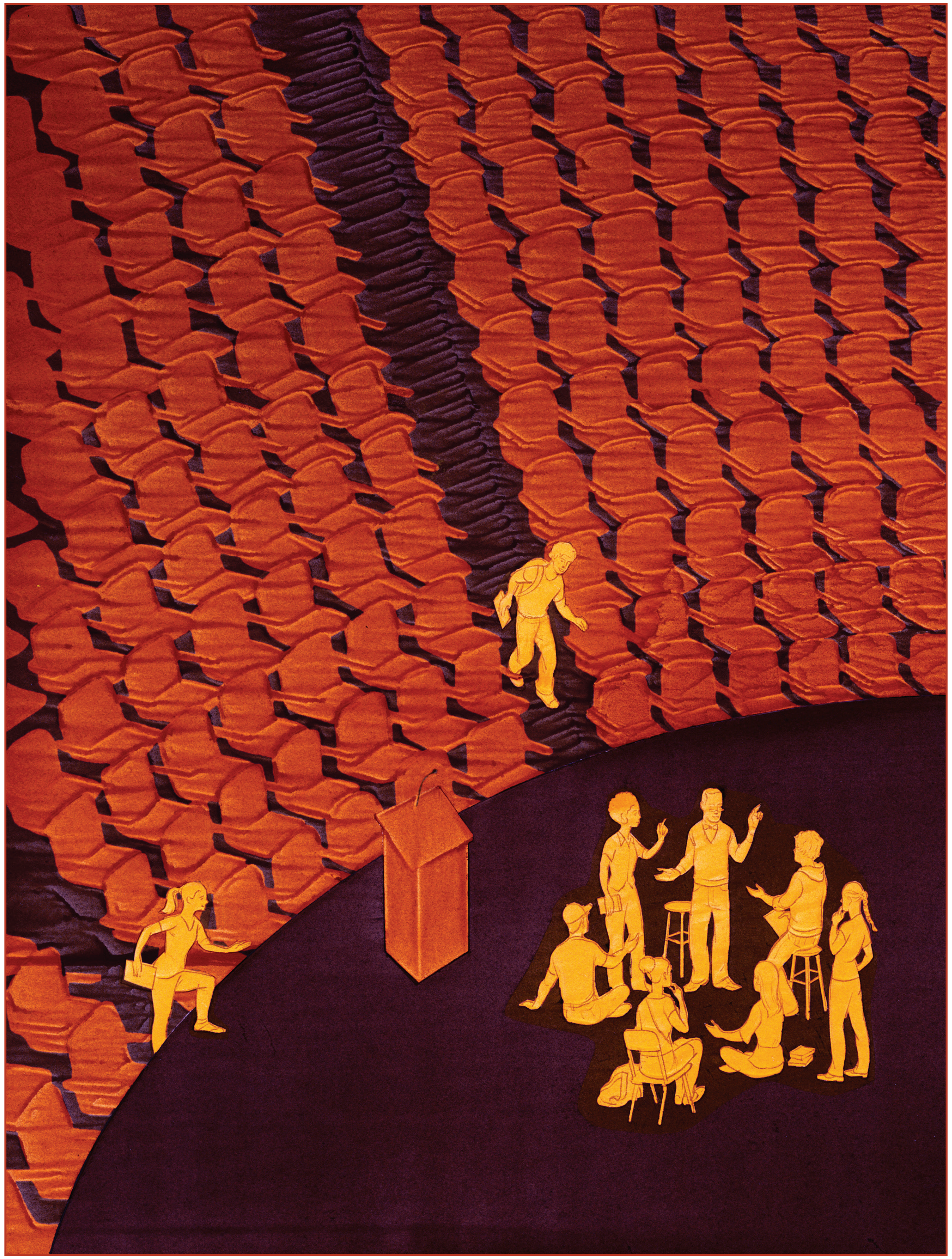

ALEX NABAUM

Should We Lose the Lecture?

TO AN OUTSIDER, the contest at the heart of Carl Wieman's 2009 experiment at the University of British Columbia might have looked laughably lopsided. On one side was a charismatic veteran professor with glowing evaluations and long experience. On the other, a postdoc and a grad student who'd served only as teaching assistants.

Who would do a better job of teaching beginning engineering majors the finer points of electromagnetic waves? Why even ask the question?

But the upstarts had rare qualifications in the academic world, where research—not pedagogy—is the usual coin of the realm. They had trained with Wieman in evidence-based instructional methods designed to make students more engaged with their own learning.

The experiment took place during the 12th week of the semester. While the professor followed the familiar format of a lecture, the postdoc's classes unfolded to a far different script, one predicated on collaboration, practice and feedback. Students broke into small groups to puzzle through problems, with instructors monitoring discussions before electronically collecting answers to gauge comprehension. Then came a short discussion before the cycle repeated with another problem.

The results—published in 2011 in *Science*—were all but a knockout. The postdoc-grad student team saw better attendance, strong reviews and, most impressively, a wholesale jump in performance. Their class did twice as well as the professor's on a 12-question multiple-choice test at the end of the week. And it wasn't just the top or bottom performers who benefited; the entire distribution of scores was higher.

"I wasn't expecting that," says Wieman, PhD '77, sitting in his office in the Stanford physics department. "I don't think anyone was."

It was the extent of the rout that surprised Wieman, not who won. For years, Wieman has called for professors to change how they teach the so-called STEM courses—the science, technology, engineering and math classes that weed out so many students even as society demands ever greater proficiency in those subjects.

The long science lecture may have made excellent sense once upon a time, Wieman says. But its continued popularity defies decades of findings from cognitive science, not the least of which show our severely limited capacity to retain the volume of information regularly thrown from the lectern.

Indeed, using the traditional hour-long lecture to teach science, he says with char-

An atomic physicist makes the case for active learning.

By Sam Scott

acteristic frankness, is like relying on medieval medicine while boxes of antibiotics abound. "It's the pedagogical equivalent of bloodletting," he says.

The Proof

A renowned atomic physicist, Wieman—who returned in 2013 to Stanford, where he holds appointments in the physics department and the Graduate School of Education as well as an endowed chair in engineering—is far from the only voice to call for reform. Nor is the University of British Columbia study the only evidence.

Perhaps most exhaustively, a 2014 meta-analysis led by Scott Freeman, a biologist at the University of Washington, analyzed 225 studies and found that students in STEM lecture courses were 1.5 times more likely to fail than those in courses using "active learning," as the teaching style featured in Wieman's experiment is broadly called.

But perhaps no one has so doggedly pursued reform from so many angles as Wieman. He has founded institutes at the University of Colorado and in British Columbia to research and to train instructors; created interactive online physics simulations used around the world; pushed the matter in Washington, D.C., where he was associate director for science in the White House Office of Science and Technology Policy; and generally evangelized to—occasionally—great effect.

Peter LePage, former dean of Cornell's College of Arts and Sciences, credits Wieman—his housemate during their Stanford days—for providing not just the "why" but the "how" for Cornell's active learning initiative, launched in 2012. By developing ways to train teaching fellows to help professors, Wieman showed him how change could be implemented even in classes with hundreds of students and maxed-out faculty.

LINDA A. CICERO/STANFORD NEWS SERVICE

TEAMWORK: Wieman engages with graduate students in one of his education classes.

"Suddenly, it began to look feasible," says LePage, MS '76, PhD '78. "My realization was, 'I am going to be a negligent dean if I don't find some way to act on this information.' "

The Motivation

It helps in all these endeavors that Wieman's own scientific bona fides are beyond reproach. A Nobel Prize does that.

Wieman got the call from Stockholm in 2001, six years after he and a partner created the world's first Bose-Einstein condensate—an elusive but long-anticipated form of new matter achieved by bringing atoms within a few hundred billionths of a degree of absolute zero.

People often assume it was only then that he landed on education research, a young laureate in search of a second act. But the prize, he says, meant he could get people to finally listen to what he had to say on the topic. (He donated the prize money to physics education at the University of Colorado, where he was a professor from 1984 to 2013.)

WIEMAN, SAYS DAN SCHWARTZ, the dean of Stanford's Graduate School of Education, has an intellectual "refractory period of zero"—he'll finish a major paper at night, then wake early to work on a book in the morning. And even while he was hot on the trail of physics glory, Wieman toggled between blasting atoms and investigating his new area of interest, one originally inspired by a nagging mystery: Why were his graduate students so unprepared?

On paper many were all-stars, he says, with gilded grades and glowing endorsements. But so many of them arrived at his lab unable to think like physicists. He recalls one particular student who came to personify the concern. He was a phenom with formulas and calculations, but whenever he got stumped in the lab, he'd ask where he could read how to solve it.

"The point is that there wasn't a place to read how to solve it. That's what physics research is about," Wieman says.

And yet after spending a few years working in his lab, students usually developed into productive scientists. Wieman began to wonder if it was just a matter of maturity. Perhaps his students' brains had to emerge from a 17-year chrysalis stage before transforming into physicist butterflies.

But as a committed experimentalist, Wieman wasn't content with conjecture. He began immersing himself in existing education research and carrying out his own, tapping into a growing body of work exposing the weaknesses of science education.

In a watershed paper, David Hestenes, a professor at Arizona State University, described a simple test given to thousands of undergrads that revealed most were leaving their introductory physics courses almost as ignorant of the fundamentals of the subject as when they arrived. Many made similar discoveries using their own students, including Eric Mazur, a physicist at Harvard who would become another leading voice for change.

In Wieman's own research, he and a colleague would present "a nonobvious fact" in a lecture along with an illustration, then quiz the students a short while later. In one instance, they brought in a violin to demonstrate that its strings do not move enough air to create the instrument's sound. Rather, the strings make the back of the violin move, which in turn produces the sound we hear. Fifteen minutes later, only 10 percent of the class could recall this fact on a multiple-choice question.

Concerned it was just a reflection on his students, he repeated similar experiments with leading faculty. The result was essentially identical: around 10 percent.

"It is really hard to believe the problem when you've been indoctrinated into a system, until you actually test it yourself," Wieman says.

The Scientific Method

The repeated findings underscored an irony. Many of the world's great scientists had been teaching with scant evidence to support their methods, something they'd never tolerate in their research. A small percentage of students might flourish, often because of motivation to work on their own. But an alarming number were getting only the most superficial understanding, at a steep cost not just to their own education but to the general scientific literacy of society.

Ultimately, Wieman would come to understand that his grad students evolved into scientists in his lab not out of maturity but because they were practicing science and reckoning with its concepts as they never had before, creating their own understanding rather than parroting what they'd learned. And that was the power of active learning. With homework, students could learn the basics of new material on their own. With practice and feedback in class, they would wrestle with and come to master it.

"It's just not how the brain learns," he says. "It does not learn to do these things by watching someone write on a chalkboard or by listening to them talk."

Professors retain a central role, but Wieman sees them more like athletic coaches, putting students through strenuous, targeted practice while giving immediate feedback and direction based on performance. By confronting the problems first, the audience is more invested—and prepared—to hear what the professor has to say.

"If you experience the condition of the problem, you'll remember the an-

Many of the world's great scientists had been teaching with scant evidence to support their methods, something they'd never tolerate in their research.

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swer much better," Schwartz, the dean of the GSE, says. "Lectures have it backwards. They basically give you the answer, then you practice it."

Still, not everybody is convinced. Wieman's eldest brother, a fellow physicist, remains fairly certain he was well-served by his lecture-based education, Wieman says. "As I keep telling him, he probably would have learned better if he had done other things," he says. "It's really hard to look back and say, 'Oh, I'm not nearly as good as I could have been.'"

Indeed, one of the challenges of converting professors to active learning is convincing them of the flaws of a system in which they prospered. "It worked for me" is a common refrain, says Wieman's wife, Sarah Gilbert, a fellow physicist and collaborator who is a senior adviser at the Carl Wieman Science Education Initiative at the University of British Columbia.

The Effect

Wieman himself never had that problem, in part because lectures never worked for him. In fact, he spent most of his undergraduate days at MIT intentionally avoiding them.

Wieman arrived at the school in 1969 with a significant case of culture shock after having grown up in the backwoods of Oregon. Though his grandfather had been an influential theologian, his parents had sought a much different life. Until middle school, when the family moved to Corvallis, Wieman lived the country life of a sawyer's son, close to a logging mill but miles from the nearest store or paved road.

He wasted no time getting stuck in to life in Boston, his knack for relentless focus immediately evident on the squash court. Having never heard of the sport before he arrived, he worked his way onto the intercollegiate freshman team, where he was good enough, he says, to lose to some of the best players in the country before ruining his elbow hurling himself about. He then retrained himself with his left hand and played at a similar level.

His most meaningful experiences, meanwhile, were in the lab. Early on, a professor suggested he get involved in research, where his appetite for work and the departure of an upperclassman led to his running his own lab by the summer of his sophomore year. For a while, he even gave up his apartment to live in the lab, since it didn't make sense to pay rent for a place he never stayed.

At first, he diligently attended lectures. But there seemed to be little payoff. "The positive experience I was having in the lab, the authentic experience of doing physics, made it so clear how much of the coursework was not authentic," he says.

The political upheaval of the time was then causing havoc at MIT, as at other campuses. To Wieman's great relief, finals were canceled in the second semester of his freshman year. And in the changing atmosphere of the day, Wieman blazed a path that required precious little class time, confident he wasn't missing out.

'I always try and tell students they shouldn't let courses get in the way of getting a good education.'

LINDA A. CICERO/STANFORD NEWS SERVICE

Q&A: In Wieman's view, students learn better by confronting problems themselves before a professor offers direction.

In some ways, Wieman was the opposite of the student who would come to perplex him decades later. He was much weaker than many of his peers in formal problem-solving, but had a much better grasp of fundamentals and an absolute comfort trying to figure things out on his own.

Occasionally he reassures students who are having a hard time with differential equations. "I took it and dropped it three times, and I never completed it," he says. "I always try and tell students they shouldn't let courses get in the way of getting a good education."

Though his college background reads like foreshadowing in retrospect, Wieman says his embrace of active teaching is foremost about the powerful and widely available data and research showing the effectiveness of this method. And while change has occurred in many places, it frustrates him that the lecture system remains entrenched in many, if not most, departments.

Indeed, the benefits of active learning are so plain, it might even be unethical to re-create the British Columbia experiment today—you'd be denying a control group the advantages of superior learning. And yet, in their classrooms, many professors lecture as they like. "It's a funny situation," Wieman says.

The reason professors resist converting their classrooms appears to have less to do with any ideological interest in defending lectures than with the inertia inherent in a decentralized system where research, not teaching, has absolute primacy in making or breaking careers and reputations. And as with everything, change is scary, especially if you've never been trained in it.

'With active learning, everybody is engaged and everybody is asking questions all the time, and it's totally out of your control,' says Professor Persis Drell, the new provost. 'You just have to have some confidence you can make this work.'

"When you are lecturing and you have your notes and you know what you're going to say and the students are dutifully writing away, you are in total control of the situation," says Stanford Provost Persis Drell, a convert to active learning who is co-teaching with Wieman during winter quarter. "With active learning, everybody is engaged and everybody is asking questions all the time, and it's totally out of your control.

"You just have to have some confidence you can make this work."

Wieman's presence at Stanford is helping move along the change for professors like Drell—those who are way too busy to veer very far from their responsibilities to get up to speed. Wieman, she says, is incredibly generous with his time for those interested in making the change.

Sarah Church, a physics professor who is senior associate vice provost for undergraduate education, is among those who have tapped Wieman's expertise. Deeply unhappy with lecturing—she could see her students getting lost with no way to catch up—Church consulted with Wieman to convert her electricity and magnetism course into an active classroom.

It was a lot of work. But she was soon convinced that she'd made the right decision. Church describes an instance in which she asked groups to go to the whiteboards to draw configurations in which Gauss's Law—one of the fundamental laws of electromagnetism—could be applied.

Some made quick work of the question yet pushed on, turning the query around to focus on systems in which the law can't be used and asking why. "They were drawing electric field lines and asking questions: 'What's the difference? What's missing?' You could give them an activity and they would just run with it and come up with their own questions, which demonstrated to me they were really engaging with the material on a level they just don't if you're lecturing."

The end-of-term results were stark. Average attendance rose from about 60 percent to close to 100 percent, teaching evaluations improved, and learning gains jumped—"the best I've had," she says. "It was a much more rewarding teaching experience for me."

Beats bloodletting. ■