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## Carl Wieman and AAAS Senior Scientists: Bringing the Science to Science Education

The classic model for undergraduate science education features a lone professor standing before a lecture hall dispensing the laws and equations that students must master to advance in science, or at least to pass the class. But consider an experiment detailed by Carl Wieman, the Nobel laureate and White House adviser, during a recent talk at AAAS:

Two large classes of undergraduate students were chosen for a special week-long introductory class in the physics of electromagnetic waves. One is taught by a highly rated veteran physics professor; the other is taught by a physics postdoc with little teaching experience but with training in some unconventional methods based on recent research into how people learn.

The result: The professor's students did well enough. But the postdoc's students had better attendance, better classroom engagement, and their scores on a test at the end of the week were significantly higher. Does that seem surprising? To Wieman it is "completely understandable and predictable."



Carl Wieman

"The new view is actually the brain is quite plastic," said Wieman, the 2001 Nobel laureate in physics and now the associate director for science in President Barack Obama's Office of Science and Technology Policy. "These brains come into the classroom not really that different and in fact, they all transform in very much the same ways if they undergo the same kind of mental exercise—that 'if' is a big one in this case."

The old system, in spite of its shortcomings, was adequate for the needs of a few decades ago. Wieman said. But today, at a time when the United States has placed a premium on developing all of its science and engineering talent, that model has come to seem outmoded and inefficient. New research—and a growing body of practice—shows that students learn better when they are motivated, fully engaged, and learning in teams, with instructors guiding a process that encourages them to think and solve problems just as scientists do in practice.

"We need all students to think about and use science more like scientists," he said.

### • LINKS

[See the presentation slides](#) from Carl Wieman's lecture at AAAS.

[Read a summary](#) of "Improved Learning in a Large-Enrollment Physics Class" by Deslauriers, Schelew, and Wieman in the 11 May 2011 issue of *Science*.

[Read a summary](#) of Carl Wieman's 4 September 2009 editorial in *Science*, "Galvanizing Science Departments."

[Learn more](#) about the AAAS Senior Scientists and Engineers program.

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Wieman has emerged as one of the world's leading authorities on science instruction, and in his presentation at AAAS, he took those in the crowded auditorium on a tour of how science can be used to improve the teaching of science and to prepare a new generation of scientists for the challenges of the 21st century.

The 25 April event, "STEM Professionals and K-12 Schools: Partnerships for Change," also featured members of a AAAS partner organization, Senior Scientists and Engineers, that works to bring retired scientists and engineers into classrooms as assistants for the teachers. In 2004, the program put its first scientists, engineers, and physicians into middle schools to support teachers in Maryland's Montgomery County. Another chapter started in 2008 in Fairfax County, Virginia. Currently, 50 volunteers from the program support K-12 teachers in the two states.

"The people who are involved—the retired senior scientists and engineers and the teachers—love it, the kids seem to love it, and it has grown and has grown and taken on force," said Alan I. Leshner, AAAS chief executive officer and executive publisher of *Science*. "It's a wonderful example that I believe could be emulated in many, many places."

### **Deep Insight on Learning**

Wieman is a past chairman of the National Academy of Sciences Board on Science Education. He is also a past winner of the Oersted Medal, the most prestigious award offered by the American Association of Physics Teachers. He led development of the ground-breaking Science Education Project at the University of Colorado-Boulder, and in 2007 moved to the University of British Columbia in Canada to start a similar venture (though he maintains a 20% appointment at Boulder).

After 15 years of deep research into learning and methods of teaching, Wieman's ideas are penetrating into the culture of American science and universities, even to places governed by tradition and sometimes resistant to change.

The classic approach to undergraduate science education assumes that the brain is like a sponge. The professor exposes the students to knowledge; the knowledge soaks in. But brain research and cognitive psychology, especially in the past 10-20 years, have shown that the brain doesn't work that way.

The new research suggests that lectures are an inefficient way to impart knowledge. Better, Wieman said, for instructors and schools to understand that learning is a process of building proteins, growing neurons—"significantly changing the brain, not just adding bits of knowledge." And the most effective way to achieve these changes in the brain, Wieman said, is by exercises that stimulate this growth and change.

In this framework, motivating the students is crucial. To advance their knowledge of a subject, the instructor has to connect with their pre-existing thinking on that subject. The instructor must recognize that short-term memory is "very limited," and that achieving long-term change in understanding requires the deliberate practice of increasingly difficult problems along with feedback by a mentor.

The goal of these efforts is to get students to think like scientists. And so, Wieman said, they must be placed in situations requiring them to think like a scientist; that challenge must be "extended and strenuous," with timely and specific feedback from the instructor. Science courses that have made students think more like experts, he said, often "are ones which are quite explicitly designed to make the process of science and the relevance of the material very explicit, and not just talking about it, but having it really lead the discussion."

### **From Concept to Application**

How does this process look in the classroom?

The top-down method of dispensing knowledge is largely set aside. The professor is no longer a lecturer, but in some senses a "cognitive coach."

To begin a lesson, Wieman assigns students a few pages of reading, followed by an online quiz to be sure that they finished it. He then poses a multiple-choice question based on common misconceptions of mental models; they choose answers with clickers, a wireless teaching tool that records their answers. While they're not graded on those answers, making the choice gives the students a sense of accountability and helps them process the question differently. That primes them for learning.

After they answer the question, students form small consensus groups around their chosen answers, discuss their reasoning, and re-vote. "And while they're having those discussions," he explained, "I'm busy running around, listening in." That gives Wieman a sense of what students do and don't understand.

Recognizing misconceptions—that's a crucial role for the instructor. Where there are consistent student difficulties, Wieman works to address the misconceptions and inaccurate mental models. "Changing mental model requires active mental process and effort," he explained. "Passively listening to explanation is ineffective."

Following the small-group discussions, Wieman leads a class-wide conversation around the questions before finally demonstrating which answer was correct by performing an experiment.

The students' follow-up questions show whether they understand the concepts, Wieman said. They're trying to understand ideas—why, for example, does the light in their dorm room might dim when they turn on the heater?

With those questions, "they're really covering new material, they're testing their mental models," he said. "They're extending this material into new areas. So they're really much more engaged in kind of intellectually thinking about this." Wieman describes his own talking in the class as "all reactive—it's in response to guide their thinking and questions."

It is by this process of engagement, challenge, repetition, and further challenge that the students begin to think like scientists.

"Don't waste class time with the instructor being an expensive talking textbook, okay?" Wieman said. "You want students to be able to learn information other ways than listening to the instructor anyway, and so if you remove that out of class, it turns out that you free up a great deal of time. But also then, ultimately, you learn how to learn things."

### **"You're thinking like scientists!"**

While Wieman's work is focused on undergraduate physics, he said he is "quite confident" that these principles apply to other fields of science and at all educational levels.

And in the discussion that followed, those involved in the Senior Scientists and Engineers program made clear that they, too, are focused on providing students with motivation and tying science to real life. Jack Byers, a retired mechanical engineer, said that Sally Berman, a teacher at Island Creek Elementary School in Alexandria, Virginia, explains Newton's forces to her students using seat belts as an example.

Nsombi Brown, a teacher at Georgian Forest Elementary School in Silver Spring, Maryland, described the special insight that mechanical engineer Dave Weiss brings into her classroom. "When there is a laboratory activity or there's a discussion going, Mr. Weiss comes in with expertise and he always relates it to real-life and the curriculum as well," Brown explained. "So, if we're talking about the revolution of the earth, he's going to relate it back to a topic that we studied in the beginning of the year on periodic motion" and the movement of hands on a clock.



Nsombi Brown

"He gets excited. He says, 'You're thinking like scientists!' That encourages them to continue

asking questions.”

Robert Thomas, a science writer who's retired from his career as an analytical chemist, ties science to current events when he volunteers with Mary Baker, a teacher at Sherwood High School in Olney, Maryland.

“We're bringing in scientific topics which appear in the media,” Thomas said. “So if anything is interesting that's on the television or in the newspaper, I'll sit down with Mary and the other chemistry teachers and we'll decide what would be suitable.

“Examples of the talks I've given there have been a talk on extraction of natural gas, a talk on the *CSI* crime series, and particularly the analytical instrumentation that has been used. I'm currently doing a talk on nuclear energy and relating it to the events at the Fukushima Daiichi power plant in Japan.”

Haddox Sothoron, an orthopedic surgeon, developed a method to determine whether he was keeping students' attention in the classroom. “The index I use for how interesting I was is how many heads were on the desks,” he said. “One, I thought, was probably acceptable. Two was worrisome, and three meant I was in trouble. So I tried to keep no more than one head down on the desk at any time.”



Robert Thomas

Thomas said he had “more than two or three heads dropping” when he first started. But “since we started talking about stuff that's occurring in the media,” he said, “the kids have really opened up.”

Despite the occasional heads on the desks, Thomas said that volunteering had been an “extremely gratifying” experience. “You create a relationship with your kids,” he said, “and when that happens it becomes very fulfilling and very rewarding for the teacher, the student, and the volunteer.”

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