FOCUS: EDUCATION — CAREER ADVICE

Changing the Science Education Paradigm: From Teaching Facts to Engaging the Intellect

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Dr. Jo Handelsman, Howard Hughes Medical Institute Professor in the Department of Molecular, Cellular and Developmental Biology at Yale University, is a long-time devotee of scientific teaching, receiving this year’s Presidential Award for Science Mentoring. She gave a seminar entitled “What is Scientific Teaching? The Changing Landscape of Science Education” as a part of the Scientific Education Colloquia Series in spring 2011. After dissecting what is wrong with the status quo of American scientific education, several ideological and practical changes are proposed, including active learning, regular assessment, diversity, and mentorship.

INTRODUCTION

From high school students to the general public, how we teach science in the United States is in need of a makeover. Recent assessments, including the 2009 Programme for International Assessment (PISA†), found that among 33 developed and developing countries, the United States ranked just average in scientific literacy among high school students [1]. In the U.S. general population, only 28 percent qualify as scientifically literate, meaning that they are able to understand the science section of the New York Times [2]. These results have come to the attention of the highest levels of government. In this year’s State of the Union Address, President Barack Obama put education, and in particular STEM (Science, Technology, Engineering...
and Mathematics)-based education, at the forefront of his Winning the Future agenda. His mantra has been “out-innovate, out-educate, and out-build the rest of the world.”

During the same week, President Obama honored some of the nation’s best science mentors. One of the 11 recipients of the Presidential Award for Science Mentoring was Dr. Jo Handelsman, Howard Hughes Medical Institute Professor in the Department of Molecular, Cellular and Developmental Biology at Yale. Besides running a microbial ecology laboratory, she devotes much of her time to developing and implementing classroom techniques to teach and excite not only scientists, but also future politicians, doctors, and writers about science.

Handelsman gave a seminar entitled “What is Scientific Teaching? The Changing Landscape of Science Education” as part of the Scientific Education Colloquia series at Yale in spring 2011. She talked extensively about the current state of science education at the collegiate level, focusing on what needs to change and giving examples of successful practices. I spoke with Handelsman following the seminar about improving science education in America.

THE CURRENT PARADIGM: WHAT IS ITS GOAL?

Many have taken an introductory college biology course. The norm is a cursory overview of disparate topics in biology, from ecology to biochemistry. The goal is to show students how diverse biology is, sacrificing depth for the sake of width. Handelsman argues that instead of showering students with facts from disparate sub-disciplines, teachers should ask what are the most important facets of biology and how can they incorporate those into the curriculum? Rather than having students memorize that DNA had two strands and four bases, can they spark their curiosity about science?

Setting goals is crucial for science education because it determines class structure. The bulk of current science education, Handelsman notes, is an inactive learning process, a one-way information transfer. This is epitomized by the classic lecture format. While lectures can help students grasp concepts and facts, it is the least effective in exciting students about science. In the “backward design” proposed by Handelsman, setting goals precedes development of content.

THE CURRENT PARADIGM: WHY IT MUST CHANGE

Many vocations require the critical thinking and analytical problem-solving skills learned in basic science classes. Meanwhile, science majors are embracing more diverse career paths. Sixty percent of biology majors do not pursue biology-related careers. Therefore, professors must better prepare students for opportunities in different fields. While many know about the medical profession, fewer realize the breadth of biomedical research and even fewer realize the demand for scientific writers who can communicate complex biological discoveries to the general populace. Scientists are also needed to advise and become policy makers in the government.

Moreover, the welfare of our democracy depends on scientific understanding. We often engage in dogmatically and emotionally charged debates about global warming, stem cell research, individualized medicine, and abortion. However, what we need in order to draw pragmatic conclusions is scientifically sound conversation concentrated on facts. Scientific literacy enables us to sift through the plethora of information and separate fiction from fact, allowing fact to guide opinion and, ultimately, policy.

Conventional science instruction is much less effective than one would hope, with only 10 to 20 percent of lecture content actually retained by students, to the dismay of the professors who spend hours explaining to their students. While retention is still under debate, active learning, Handelsman claims, has proven to be more effective [3,4,5]. Additionally, while students do learn some biological facts from lectures, they often fail to understand them in a broader
context. As a result, students are puzzled by wordy test questions that ask them to synthesize or analyze seemingly unrelated facts for the first time. Tests should not be the only place for students to connect scientific facts into coherent ideas; scientists synthesize disparate topics to pose hypotheses and solve dilemmas every day. Handelsman argues that the classroom could be an incubator for ideas, allowing students to assume the mentality of a scientist.

Unfortunately, scientific understanding is not a strength of the United States. As discussed in Handelsman’s talk, when a group of graduate students at the University of Wisconsin ventured into the community and recorded people’s responses to basic microbiology questions, the lack of scientific literacy in our society was readily apparent.

For all of these reasons, we need better methods of educating Americans about science. I asked Handelsman if we should increase science requirements for all college students. She cautioned that it is not necessarily the quantity, but the quality, that needs improvement. If students take a meaningful and engaging course at the collegiate level, they should walk away scientifically literate and with a deeper appreciation for how science works.

THE FUTURE PARADIGM: EMULATING THE SCIENTIFIC PROCESS

The future of science education is already here. Examples include a class that Handelsman spearheaded at Wisconsin called the Teaching Fellows Program. The fellows take an 8-week course entitled Teaching Biology to develop and implement their own curriculum in the classroom [6]. This is also being done at Yale, where students who took the class in fall 2010 co-taught a biology for non-majors class called Genes and Environment in the spring. Moreover, Handelsman and others have developed a summer curriculum at the National Academies Summer Institute on Undergraduate Teaching in Biology to help train and improve undergraduate educators. The Institute brings together educators from research-intensive universities to focus on improving teaching [7]. So far, the Institute includes more than 250 faculty who teach approximately 100,000 students annually.

But more must be done. Handelsman talked at length about basic steps that have been demonstrated to improve student learning: active learning, regular assessment, diversity, and mentoring opportunities [8,9].

Methods of encouraging an active learning curriculum include clicker use, small group discussions, index card questions, and many others that can be easily implemented in the classroom [10]. Clicker questions force students to synthesize information that has been discussed and give the professor instant feedback on how the class is grasping concepts. Meanwhile, small group discussions help students express their thoughts and solve problems in a way that emulates the scientific process. Furthermore, those who are intimidated by larger classes are much more likely to speak up in a smaller group, so everyone feels ownership over their learning. A final active learning method is writing concerns or questions on a note card at the end of the class for the professor, helping the professor assess what to focus on and strengthen.

One tangible example of enriching undergraduate scientific learning experience is mandatory laboratory participation. However, in traditional laboratory exercises that complement lectures, students often follow a strict set of “cookbook” steps to achieve a prescribed result. This does not accurately reflect the scientific process and may not excite students to pursue scientific disciplines. In more active exercises, such as mini-research projects, students experience the entire scientific process, from formulating questions to recording and analyzing data to deriving conclusions. Students may also substitute laboratory classes with rotations in research laboratories [5]. While this will require extra work on the part of the faculty, the benefits of introducing more students to the exciting process of science at work may be worth the extra effort. Another innovative idea is to teach a class entirely devoted to the process of being a scientist [11].
One vital aspect of effective teaching is molding the curriculum based on student learning throughout the semester. Beyond the typical midterms and finals, assessment of student understanding can come from note card feedback, as discussed above. Regular writing or problem-solving assignments also save students from getting lost during the semester. However, this method challenges the professor to remain flexible, adapting the course in order to accommodate student-learning needs.

Another key to creating better science education is to encourage diversity. Diversity is crucial in the scientific enterprise because it brings divergent views to the table, allowing formulation of the most pragmatic and often best solution to the question at hand. In the classroom, diversity would encourage group discussions in which opposing viewpoints have to be considered and ultimately resolved in the problem-solving process.

Lastly, mentoring provides the students with an enriching perspective. Students are often intimidated by professors and would benefit from talking with an older student within his or her discipline about questions and concerns. Programs that make mentors available to younger students make it possible for more students to learn about opportunities in diverse scientific fields. One example is the Women in Science at Yale (WISAY) program, which pairs an undergraduate with a graduate-student mentor. Furthermore, training programs for mentors help ensure a mutually rewarding experience for the mentor and mentee [12,13]. Handelsman has organized a half-semester mentoring skills workshop at Yale, and many additional workshops are also periodically held at the Center for Scientific Teaching at Yale.

CONCLUSION

At the end of our discussion, I asked Handelsman why these ideas have not been implemented more frequently. Often, she said, professors do not want to leave the comfort zone of their teaching methods. They also sincerely believe that they are helping the students understand science, especially because lectures are modeled on how they learned when they were students. While some students learn well from lectures, the data suggest that many do not, and even for those students who do learn well in this fashion, their learning could be enhanced by additional methods [10]. To encourage more active learning, incentives may be needed for teachers to change practices. In many universities, research is regarded as the bona fide top priority. Rather, large research-intensive universities should reward excellence in teaching to the same degree as excellence in research [14].

In sum, recent data suggest severe scientific misunderstanding in the American society, even though the world we live in is becoming increasingly scientific. The opportunity is ripe to change science education for the better.

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