Presidential Report Draws Criticism from Mathematicians

Allyn Jackson

In February 2012 the President's Council of Advisors on Science and Technology (PCAST) issued a report about the need to increase the number of college students majoring in scientific and technical areas. A rumble of consternation erupted among mathematicians, who were startled by the report's suggestion that college math instruction could be improved by having faculty from outside mathematics develop and teach mathematics courses. All of the major mathematics organizations in the United States, including the American Mathematical Society (AMS), have issued statements that, while praising many aspects of the report, take exception to some of its recommendations. Exactly what effect the report may ultimately have is unclear. One immediate result has been the initiation of dialogue between PCAST and the mathematical sciences community.

Controversial Recommendations

Titled *Engage to Excel*, the 106-page report argues that, over the coming decade, the nation needs to prepare a million more workers in science, technology, engineering, and mathematics—the so-called STEM areas—and makes specific recommendations for how the federal government can stimulate efforts toward this goal. Because many students leave pathways to STEM careers not long after secondary school, the report focuses on improving STEM instruction in the first two years of college. This is a time where students often fall into what the report calls the "math preparation gap": the gap between the math background students need for STEM majors and the math background they actually possess.

One of the report's five recommendations focuses on this gap, proposing "a national experiment in postsecondary mathematics education." The report suggests that the experiment include a variety of approaches and offers four specific possibilities, one of which is "college mathematics teaching and curricula developed and taught by faculty from mathematics-intensive disciplines other than mathematics, including physics, engineering, and computer science." To many mathematicians this sounded like a call for engineers and scientists to take over the first two years of college mathematics teaching. "What PCAST should have done is called for renewed efforts by mathematicians to reach out to other educators of students preparing for STEM careers in order to determine what is required by these students, what they are learning, and how to improve their performance," said AMS president Eric Friedlander of the University of Southern California. "For many reasons, mathematicians should play the central role in such efforts."

One of the other suggested approaches to the "national experiment" also struck many mathematicians as problematic: "a new pipeline for producing K–12 mathematics teachers from undergraduate and graduate programs in mathematics-intensive fields other than mathematics." Tara Holm of Cornell University, who chairs the AMS Committee on Education (CoE), said this idea struck her as "even less feasible and more outrageous" than the one about having nonmathematicians teach the first two years of college math. The question of what K–12 mathematics teachers need to know and how best to impart that knowledge to them is a difficult and subtle one that mathematicians and experts in mathematics education have struggled with—and fought over. Said Holm, "I don't see how PCAST could imagine that people outside of mathematics would have a sense of what K–12 math-specialist teachers would need."

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Lack of Awareness

Another drawback mathematicians found in the report is a lack of awareness of mathematicians' current activities in education reform. In this regard, the report's treatment of the laboratory sciences is quite different. In discussing its recommendation to replace traditional lab courses with "discovery-based research courses", *Engage to Excel* cites several studies showing that these kinds of courses increase students' understanding and enthusiasm and stimulate them to persist in STEM coursework. One of the appendices is devoted to highlighting two projects—one at the University of Texas at Austin, the other at the University of California at Davis—that have successfully used discovery-based science courses to attract and retain students in STEM majors. The general impression the reader gets is that, while there is plenty of room for improvement, there is also a degree of consensus about how lab courses should be revamped and that academic scientists are actively involved in improving collegiate science instruction.

By contrast, no examples of mathematicians' views about and activities in teaching reform appear in the report. No mention is made of, for instance, the Mathematical Association of America (MAA) Committee on the Undergraduate Program in Mathematics (CUPM), which, for more than half a century, has had a large influence on undergraduate mathematics teaching. The CUPM has a subcommittee called CRAFTY (Curriculum Renewal Across the First Two Years), which has held a series of workshops to stimulate conversations between mathematicians and faculty outside mathematics about how math courses can be made to better serve the needs of nonmath majors. William McCallum of the University of Arizona, former chair of the AMS Committee on Education, served on CRAFTY in the late 1990s and participated in some of those workshops. He noted that *Engage to Excel* repeats much of what mathematicians were saying about teaching reform at that time. In fact, he noted, "Conservative engineers and scientists often supported the fierce resistance to calculus reform from some mathematicians." CRAFTY's work continues; its latest report, *Partner Discipline Recommendations for Introductory College Mathematics and the Implications for College Algebra*, appeared in 2011 (see `http://maa.org/cupm/crafty`).

There are many other projects in the math community that aim to improve undergraduate math teaching. Examples are included in the mathematical sciences organizations' responses to the PCAST report, and the AMS has begun to build a webpage listing ongoing projects. Are these things difficult to find out about? "It's not so difficult," said MAA president Paul Zorn of St. Olaf College. "If [the report's authors] had consulted with people who are knowledgeable about what the math community is doing, they would have found these things out." MAA executive director Michael Pearson pointed out that one reason for the report's silence about activities in the mathematical community could be the way writings about such activities are published. They appear in, for example, the MAA's Notes and Reports series rather than in journals. "Other disciplines have created peer-reviewed channels for making discipline-based education efforts part of the record and thus more visible and readily accessible," he said.

Pearson noted that the report seems to overstate the existing shortcomings in mathematics instruction and to imply that students' lack of persistence in studying STEM areas is almost solely due to poor mathematics instruction. "The problem is much more complex than that," he said. "Improving mathematics instruction will require active engagement of mathematicians and a commitment of resources—for example, for teacher education and professional development, as well as for amelioration of gross economic inequity—at levels policymakers seem unwilling to make in the current political and fiscal environment."

Another drawback of the report is that it conflates two different issues, Friedlander noted. One is that many students leave high school with a mathematics background that is inadequate for tackling college-level mathematics courses. The other issue is the need to improve those courses to ensure that students majoring in STEM areas have the knowledge they need. As a result, he said, the report seems to set up an unrealistic expectation that colleges can "take students who are uncomfortable manipulating fractions, introduce them to the beauty and usefulness of mathematics, encourage them to engage in 'discovery', not burden them with tasks they view as onerous, and yet empower them to launch their STEM careers."

Agreement on the Big Picture

S. James Gates, a University of Maryland physicist and PCAST member, is one of the cochairs of the working group that produced *Engage to Excel*. When he was asked about the recommendation of having faculty outside of mathematics design and teach math courses, he conceded that the wording had unfortunately left room for misinterpretation. "Some thought that [this recommendation] meant we don't want mathematicians involved," he said. "That's not the case. We want to have mathematicians, who are the true masters of the field, engage with people who are consumers of mathematicians' output. We are working hard to get mathematicians involved." He said that the PCAST committee hopes to stimulate interaction between mathematicians and faculty in other disciplines to look carefully at what is needed in courses that sit at the boundary between mathematics and other fields.

When asked about the recommendation for new pathways for K–12 teachers, Gates emphasized that this is only one possible approach and acknowledged that the working group did not have a tidy solution for the complex problems of K–12 mathematics education. Nevertheless, "we wondered whether having people who are highly skilled in math but who are not necessarily aiming to become mathematicians might be closer to what is needed for K–12 math." He noted that math majors study areas of mathematics that are distant from K–12 mathematics and far more technical. "I can't put a metric on this," he said, "but the distance from that to teaching K–12 is bigger than for someone who, for example, studies quantum mechanics and learns the mathematics needed for that and then goes into K–12 teaching."

Gates said there would be plenty of opportunity to consider details of specific recommendations, but it is crucial to focus on the big picture. He noted that the United States has in recent decades lost millions of jobs that used to sustain the middle class. The future prosperity of the nation depends, he said, on the creation of a "STEM-capable workforce"—this includes not just scientific elites but also people who use knowledge of STEM areas in their jobs. Because mathematics is central to the training of such workers, the "mathematics preparation gap" is a major issue. "We recognize that this is a complex problem and that many in the mathematical community have tried to deal with it," said Gates.

Mathematics organizations' responses to *Engage to Excel* indicate that the mathematical sciences community basically agrees with this big-picture view. Friedlander comments that there are at least two fundamental problems that mathematicians are trying to address. The first is to raise the level of mathematics preparedness of students entering college; an important aspect is improving the education of K–12 mathematics teachers. The second is to inspire and retain students who might enter STEM careers while providing them with the necessary knowledge and skills. To do this, he said, mathematicians continue to reach out to colleagues in mathematics-intensive fields, both to ascertain what mathematics is useful in these fields and to supplement their teaching with relevant applications.

Zorn of the MAA noted that although there was plenty of "kvetching" over the report, "the main thrusts are very clearly ideas that we support and are working to promote." In particular, he agrees with the report's emphasis on "evidence-based" methods for improving teaching. "There are approaches to teaching science and mathematics that are known to be more effective for many teachers than the standard ways," he said. "We are not all still scratching our heads over this." For example, there is a research base of evidence showing that student-centered teaching methods are very effective. To understand and promulgate such methods is a task the mathematical sciences community is actively pursuing, he said. He also agreed with some parts of the report's proposal for a "national experiment" in postsecondary math education, in particular, the call for the federal government to support two hundred 5-year experiments at an average cost of US$500,000 each. Zorn called this "an excellent idea…. I hope it happens."

Math Organizations Issue Statements

All of the major mathematics organizations in the United States have come out with statements about the report: the AMS, the American Mathematical Association of Two-Year Colleges (AMATYC), the Association for Women in Mathematics (AWM), the MAA, and the Society for Industrial and Applied Mathematics (SIAM). All of the statements express agreement with the report's call to improve STEM education, and all pointedly criticize the report's treatment of mathematics. The AMS statement is posted on the Web (`http://www.ams.org/policy/govnews/pcast-statement`), and the "Opinion" column in this issue of the *Notices* presents a distillation of the views in that statement.

The reception the report has had in the mathematical sciences community seems to have been quite different from that in other areas of science. On the day the report was released, the American Physical Society (APS) and the American Chemical Society (ACS) issued news releases praising the report and aligning themselves with its recommendations. The APS release noted that one of its own programs is mentioned in the report.

In fall 2011, as preparation of *Engage to Excel* was entering the final stages, Gates made presentations before some mathematical sciences groups, including the AMS Committee on Education. Those presentations evidently did not prepare committee members for what the report would say about mathematics. After the report appeared, word about the controversial recommendations percolated through the mathematical sciences community. CoE chair Tara Holm said she first found out about them through the AWM Facebook posting that appeared about three weeks after the report's release. AWM president Jill Pipher of Brown University made the posting after hearing from Rebecca Goldin of George Mason University, who had found out about the report from a colleague. Goldin had a long discussion with PCAST executive director Deborah Stine and wound up at a PCAST meeting presenting testimony about the report on behalf of the AWM Policy and Advocacy Committee. Pearson of the MAA also gave testimony after the report's appearance.

After it became clear that the mathematical sciences community had serious reservations about how its subject is treated in the report, Gates began

reaching out to leaders in the community to hear their views. In April 2012 he met with the Joint Policy Board for Mathematics (JPBM), a collaborative group of leaders of the AMS, the MAA, the American Statistical Association, and SIAM. MAA president Zorn attended the JPBM meeting and said the discussions with Gates were cordial. "But there was this elephant in the room," said Zorn. "Why were all these things said in the report about mathematics and mathematics teaching without taking due account of the things that have been done and are being done by mathematicians?… Mathematicians were quite puzzled as to why we had so little impact on the report."

One probable reason is the lack of representation of mathematics on PCAST. Closest to the subject is PCAST cochair Eric Lander, a leading genomics researcher who founded the Broad Institute at the Massachusetts Institute of Technology. Lander received a Ph.D. in mathematics from Oxford in 1980 and soon thereafter moved into biology; he has fourteen publications in MathSciNet versus over four hundred in PubMed, the online citation index for biomedical literature. No mathematicians were appointed to the working group for *Engage to Excel*.

The report contains a list of "Experts Providing Input to PCAST", and on that list are some mathematicians: former AMS executive director John H. Ewing, who is now president of Math for America; Samuel M. Rankin III, director of the AMS Washington office; and MAA executive director Pearson. Ewing provided reactions to some early thoughts the working group had about how to approach mathematics in the report, and Rankin supplied some statistics from the Conference Board of the Mathematical Sciences. Pearson contacted PCAST on his own initiative to offer information and assistance from the MAA. He said that after reading the report it appeared his input had had no influence. Three others in mathematics education are also listed as experts consulted by the working group: Uri Treisman, director of the Charles A. Dana Center at the University of Texas at Austin; Joan Ferrini-Mundy, who heads the National Science Foundation's (NSF) Education and Human Resources directorate; and James Lightbourne, a senior adviser in that directorate.

What effect is the report likely to have? Certainly many PCAST reports have disappeared into desk drawers and had little impact. Whether *Engage to Excel* will meet a similar fate is unclear. It makes specific recommendations, with dollar amounts attached, for programs that the federal government could create. For its suggestion to support two hundred 5-year experiments to improve college mathematics teaching at an average of US$500,000 each, the report suggests the NSF and the Department of Education as possible funding sources. Three months after the report appeared, Ferrini-Mundy of the NSF issued a "Dear Colleague" letter calling for input on how to use US$60 million that is slated in the fiscal year 2013 federal budget for K–16 mathematics education programs at the NSF and the Department of Education. The letter did not specifically mention *Engage to Excel*, but given the timing of the report's appearance, it seems reasonable to expect that the report could influence the use of that US$60 million. "Certainly the report provides important perspectives on how to improve science, technology, engineering and mathematics education at the undergraduate level," said Ferrini-Mundy. "Undergraduate STEM education is an ongoing area of focus for us, and NSF is studying the report and its recommendations carefully. We are also continuing to review the many excellent suggestions we received from the community in response to the Dear Colleague letter."

Meeting the Challenge

McCallum said he suspected that *Engage to Excel* might have been intentionally provocative to get the attention of mathematicians. It not only got their attention, he said, but it got a "full-throated tribal response". To achieve the goals of the report, what is needed is a powerful coalition of all faculty devoted to improving undergraduate education in STEM fields—a coalition that will be impossible to build "if the mathematicians and scientists are fighting it out." Said McCallum, "My feeling is that the correct response is to try to calm things down a bit, put out information about the extensive efforts by mathematicians at improving undergraduate mathematics education, admit with some humility that these efforts have not been as successful as we might like, and welcome the aid of people in other STEM fields."

Engage to Excel was written in a spirit that recognizes the beauty and importance of "the incomparable human language—mathematics," said Gates. "We regard our mathematician colleagues as a deep well of expertise, ability, and intellect, and we are making a call to apply their intellectual creativity to this problem…. We are not trying to be prescriptive. We don't know all the answers. We want people to work with us, because if we don't meet the challenge, then the United States will be a very different place from the one where we grew up."