

Transforming Post-Secondary Education in Mathematics (TPSE Math)

Institute of Pure and Applied Mathematics
University of California at Los Angeles
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Report of a Meeting

Gene Block
Chancellor, UCLA

Chancellor Block opened the meeting by welcoming the participants and expressing his delight in hosting a “national conversation on the challenges facing higher education in mathematics.” He noted UCLA’s “struggle” to recruit more students from inner cities, and the challenge of attracting them to science and engineering. “This is partly due to weaknesses in STEM education,” he said, adding that the reforms being discussed by TPSE Math were a critical step in promoting equity of opportunity.

Mark Green
Professor Emeritus of Mathematics, UCLA
TPSE Math

Prof. Green offered an introduction to TPSE Math, saying that its six current members had “come to it by different paths” and that this diversity unites the group. He said they shared the belief that work in post-secondary education needs to be done, and that this is “a real time of opportunity” for doing so.

“Our community and the country are ready to make major change,” he said. “This is a moment where the intellectual situation of mathematics could not be better.” Current progress in fundamental math, he said, was “astonishing,” and the uses of math were expanding rapidly. “The needs of scientists go beyond standard math to sophisticated things, so that math has become a driver of progress in other disciplines. This brings more responsibility to the mathematics community, because more careers depend on the knowledge and skills of math. TPSE is here to try to galvanize this movement without channeling in it any narrow direction.” He quoted TPSE Math member Uri Treisman, who said, “We are aiming for coherence without uniformity.”

The purview of TPSE, he concluded, is the entire range of post-secondary institutions. “We’re especially glad to have the leaders of AMATYC,” the organization representing mathematics in two-year institutions, and noted “our goal at each meeting is to reach out to new people.”

Eric Friedlander

Chair, Department of Mathematics, University of Southern California
TPSE Math

Prof. Friedlander emphasized the objective of “trying to actually do something, not write reports. It’s too late to stand back and say there should be a study.”

Mathematics is important both for society, he said, and for young people, “no matter where they want to go.” It is also crucial for people from underrepresented groups and diverse backgrounds. “Math is not a backwater; it is central to what is important in society. Not only majors, STEM PhDs, and engineers need math; we all do. Our challenge is to equip all students with the math they need.”

TPSE hopes for a holistic approach, he said, providing “connective tissue to the mathematics enterprise.” But we still need to know more about who are we teaching, why our students need help in math, and which teaching methods can improve student outcomes.

This will require many approaches, he said – not one magic bullet. The task is to identify those approaches, evaluate them, and share them among many groups. TPSE hopes to offer a framework for discussion of these approaches and others not yet known, and then to scale them up, increase the capacity for change, and expand the networks that promote change.

Many departments are using new topics, teaching methods, and materials, he said, and the task is to “seize what’s good” and build upon it. This requires organizations and people with the experience and commitment to do this, and who are rewarded for doing so.

He stressed the growing needs of non-traditional students. Out of some 18 million undergraduates, only about 5.2 million are traditional four-year students; the rest are in other categories, primarily two-year, part-time, “over -21,” and students enrolled in for-profit institutions. The needs of this population have proliferated along with its size, and the uses of mathematics have expanded from the traditional quantitative sciences to economics, communications, data sciences, life sciences, and everyday life.

Pressures for change are felt from many sides, including newer learning techniques, such as active learning; new teaching technologies, such as MOOCs; exhortations from major national studies; and the encouragement of federal agencies and non-profits.

After regional meetings with diverse members of the mathematics and academic communities, he said, TPSE Math recommends several strategic directions: leveraging support from governments and foundations, highlighting successful innovations, organizing networks of concerned leaders, and maintaining links with professional societies, state and federal governments, and foundations.

More specifically, these strategies point to a series of linked projects:

- Developing templates for institutional, regional, and state-level convenings;
- Development of new curriculum materials;
- Improved ways to evaluate reforms;
- Gathering data on direct economic benefit of mathematics;
- Case studies of experiments and innovations.

He emphasized the strong need for improved evaluation of teaching and learning techniques. “We’re way behind on this; we don’t really measure – even though we’re mathematicians!”

He closed by noting the challenges facing TPSE and others who believe reforms are necessary, including the large number of underprepared students, outdated curricula, and resistance to new teaching methodologies. Positive change, he suggested, may depend on new incentives for excellent teaching, increased cooperation with other disciplines, and other strategies that depend on much more collaboration and networking in a field traditionally reluctant to change.

Panel 1: The Role of Mathematics in Preparing for Careers of the Future

Mark Green, UCLA & TPSE Math (Chair)

Sabrina Schmidt

Data Manager, Time Inc.

Sabrina Schmidt, who recently graduated from Vassar College with a dual major in mathematics and Italian, spoke about how she found a rewarding job as data manager at Time Inc. – and reflected on how she feels her math studies could have prepared her even better for the workforce.

After graduation, she wanted to use her math skills in the entertainment or music industries, and found this position, in which she manages store-level distribution for *Us Weekly*, *Rolling Stone*, and *Men’s Journal*. She determines how many copies go into which stores, using formulas based on the stores’ available checkout pockets and average sales.

After seeing the diversity of math applications in magazine publishing, she said, she believes students could receive more guidance about career options. “My college textbooks were mostly filled with theorems, definitions, and proofs,” she said, “and barely any examples of applications. I feel that I didn’t think or learn enough about connections to real-world uses.”

She listed many practical examples of issues that might catch students’ interest: the role of eigenvectors in Google’s PageRank algorithm; how encryption uses number theory to facilitate Internet commerce; and the role of math both in rapidly growing areas (e.g., web development and social networks) and in fields where math’s long-time importance continues to grow (e.g., aviation and national security).

Because so much math-based STEM work, such as compressed sensing and drug design, is multidisciplinary, she recommended that majors be required to take at least one course from another STEM field. She also suggested better departmental collaboration, including joint courses that could count for credit in more than one discipline. “A class using computer science skills to analyze large data sets could be applied to either a computer science or math major.”

She said that she and many classmates wish they had taken more data-driven courses rooted in applications, and offered a menu of suggestions:

- Every student interested in pursuing a math degree should be required to take at least one statistics course. “My job requires a quantitatively astute person, who can make conclusions from large data sets.”
- Students should be introduced to more advanced heuristic methods; there is a higher demand than ever for employees who are proficient in working with big data.
- Students should take at least one computer science course. “I wasn’t aware of how vital programming and coding are. They help bridge the gap between theory and practical application.”

She concluded by saying that her employer is “betting on big data,” such as the ability to deliver more targeted advertising. “More data than ever is collected and analyzed” about sales, demographics, day of delivery, shopping habits, and other features of the business. “They need employees with statistical and computational expertise. In the 21st century there will be surprising connections between math and other fields. Students need to be better prepared by building on core math concepts through real-world applications and interdisciplinary links.”

Matt Ando

Chair, Department of Mathematics, University of Illinois at Urbana-Champaign

Prof. Ando, an active participant in TPSE events and a national leader in post-secondary reforms, has chaired his mathematics department since 2011. His department, which already had 1,100 math majors, was thrust into an experiment in interdisciplinary collaboration when the engineering department expanded and needed improved mathematics. In addition, 80 percent of the enrollment in math classes represents majors in departments other than math. When the size of the engineering department surged half a decade ago, it caused the enrollment in engineering calculus to rise from 400 in 2007 to 600 in 2014.

At the same time, engineering students had complained that their training in calculus did not prepare them for multivariable calculus classes taught by the mathematics department. Prof. Ando’s response was to propose a collaborative effort with the engineering faculty. A central feature was to jointly design the engineering worksheets with problems to be solved by calculus.

These sections had many distinctive features. College of Engineering buy-in helped establish the course, along with some financial support for extra TAs. Faculty agreed to stay with the course

for at least two years. TAs were prompted to form the groups quickly and randomly, and to “avoid lecturing.” Students now work in groups of four while faculty members rotate through the sections, with each course having at least one faculty member experienced in that course. Incentives have attracted tenure-track faculty, as well as long-term instructors, and brought “huge improvement.”

The strategy has generally worked, he said, with one caveat: “Collaboration is valuable, and collaboration is time-consuming. It takes a sustained faculty commitment on both sides. TAs need training, mentoring, and supervision. In the beginning, we weren’t teaching what the engineers thought they needed to learn. Now the engineers are invested, and they care that we succeed.”

A more recent experiment – also successful – has been Introductory Mathematics for Life Sciences. This involves some calculus, but includes statistics, data visualization, and other areas relevant to biology. “We did this after a long conversation with the biologists,” he said. “That way we did not have anxiety about whether it was relevant.”

Another innovation is the Illinois Geometry Lab, which connects students with careers and schools. It forms teams of undergraduates with a graduate leader and faculty mentor to work on semester-long research projects, including internships and outreach to thousands of students. The internships have been so popular that the department has expanded it to PhD students, 70 percent of whom are enrolling in internships.

Additional initiatives he described were:

- A revised linear algebra course with active learning, big matrices, and collaboration with the College of Engineering
- Brief videos for large calculus courses
- Concept inventory and pre- and post-testing
- Undergraduate research for actuarial science
- Careers and internships

David Levermore of the University of Maryland said that 40% of research universities had transition courses, but the initiative came largely from the biologists. “We don’t take credit for how they should be training their undergrads,” he said. “We are the junior partner in some of these discussions.”

Celeste Carter

Program Director, Division of Undergraduate Education, National Science Foundation

Dr. Carter, who directs Advanced Technological Education (ATE), said that the ATE program seeks to promote the “education of science and engineering technicians,” primarily at community and technical colleges, “for high-technology fields that drive the nation’s economy.”

It does so through partnerships with industry, economic development agencies, and secondary and four-year institutions.

As of spring 2013, ATE supported 292 active grants in micro- and nanotechnologies, advanced manufacturing technologies, agricultural and environmental technologies, bio- and chemical technologies, engineering technologies, general advanced technological education, and information and security technologies. These projects were supported (as of 2012) by about 8,000 collaborations with business and industry. The purposes of these collaborations were to gather information about workforce needs, general support, developing program content, and financial or in-kind support.

One successful program, for example, is the Bridge to Biotech I, created in 2003 as a “learning community” composed of three classes: Research Skills for Career Opportunities, the Language of Biotechnology, and Biotech Math. The Bridge program targets populations that have no biology background, and 7th to 9th-grade math and English skills. Results include a 70.6% pass rate in non-majors biology, an 82.5% pass rate in medical chemistry, and a 96.5% pass rate in chemical principles.

Other programs include a partnership with the National Center for Manufacturing Education, working with Sinclair Community College and Wright State University, which teaches Introductory Mathematics for Engineering Applications; provides context for remedial math courses as a way to promote learning and motivation for community college students; and offers a course of work-preparedness for first-year students.

She concluded with a quote indicating the need for better coordination among programs: “...a substantial part of the high school mathematics we teach is mathematics that most students do not need, some of what is needed in the first year of community college is not taught in our schools, and the mathematics that is most needed by our community college students is actually elementary and middle school mathematics...”

Phil Daro

Co-director, Common Core State Standards

Dr. Daro, an experienced mathematics educator based in California, helped write the Common Core State Standards for mathematics, and in doing so saw “problems in the K-12 system and how universities sometimes send messages inadvertently.”

He reviewed some of the findings of his group, such as the heavy dependence on mnemonic devices (i.e., those relying on memory). “Using mnemonics is okay,” he said, “but in many classrooms it’s all that we’re teaching. Universities have to give K-12 the confidence to go deeper into fewer things.”

One of the decisions of his group, he said, was to recommend modeling. The reason for that is to enable students to “use math in a messy world.”

Some good news about the Common Core, he said, is that it is being embraced by teachers “more than we expected. They want to learn more math, but they want deeper treatment of the topics they’re teaching – not more topics. They want it to be more rigorous, but also messier too: math as it’s really used.”

Louis J. Gross

Director Emeritus, National Institute for Mathematical and Biological Synthesis (NIMBioS)
Professor of Ecology and Evolutionary Biology and Mathematics, University of Tennessee

Prof. Gross described biology as a “major driver of undergraduate education – more than engineering, and far more than math, chemistry, and physics combined.” He cited the mission of NIMBioS, which involves a “phenomenal number of different disciplines,” but noted that “there has been relatively little emphasis on the changing fields of students by the mathematics community.”

In the undergraduate landscape, he said, the greatest enrollment increase has been in social/behavior sciences, followed by biology and agriculture. While math departments have not responded to such changes, engineering has: of eight engineering departments at the University of Tennessee, four have “bio content.”

He cited a 1961 report from a conference sponsored by NIH at Western Carolina University, much of which “rings true today,” including the comment that “there is no unique appropriate quantitative education in math biology.” He noted that much the same conclusion was reached by the *Vision and Change*¹ report he co-authored and other reports, including the *Bio 2010* report released in 2002 by the National Research Council.

He urged the adoption of several lessons from such reports. One is to follow a “mixed pedagogy” of approaches – teaching students using diverse methods: symbolically, graphically, numerically, verbally, and data-driven (from observations).

What else have we learned? he asked:

- Many model programs and new curricular materials have been developed;
- Biologists are becoming more attuned to quantitative approaches; and
- Education research provides guidance on what really works.

¹ *Vision and Change in Undergraduate Biology Education* (2011), AAAS, Washington, DC (<http://visionandchange.org/>). He also cited *Mathematics for the Life Sciences*, Princeton University Press, August 2014 (<http://press.princeton.edu/titles/10298.html>), which urged a curriculum built around a diversity of topics, including data, coding, and computational approaches.

He cited several lessons for the mathematics community. One is that the life sciences are “highly integrative.” However, undergraduate programs are not addressing this reality. This offers opportunities to reconsider the quantitative components of the entire undergrad life sciences curriculum and move away from only calculus and toward statistics and a diversity of quantitative concepts as a life science requirement. “We are teaching 19th century mathematics,” he said.

He urged new opportunities for faculty, “who have hardly any time to think about service or curriculum development, or to help colleagues prioritize key objectives they like students to leave with.” The “bane of undergraduate math education,” he said, is that “it has been developed by, and mostly taught by, those for whom math came easy.”

Another issue is inefficiency in the system: most college entry-level math courses cover the same material students have seen in high school, and a significant fraction of entry-level courses are taught by graduate students who have little teaching experience and often poor English skills.

In response to these barriers, he proposed several “routes to success”:

- Put post-secondary math in some relevant context, such as biology
- Adopt approaches from other institutions that work – and celebrate the differences
- Encourage a ‘whole curriculum view’ rather than a ‘single course’ view
- Adopt multicultural mentoring for non-US-native instructors
- Support quantitative learning centers, similar to writing centers.

Discussion

Chad Topaz of Macalester College asked which of two approaches math should take in working with other disciplines: (1) to articulate it specifically with the discipline, or (2) to promote transference to many other fields. Dr. Gross said that what might be done at Macalester College would be different from what might be done at the University of Illinois. He said it was helpful to use different examples for different groups of students. He expressed frustration at the rote nature of teaching linear algebra, advising the addition of geometric context. He used Google Earth as motivation for Markov chains and associated matrix algebra describing landscape transitions to solve problems, an approach that “can be applied in many areas,” including business and social science. He begins with topics or questions, then brings in the needed math skills.

Dimitri Shlyakhtenko, chair of the UCLA mathematics department, asked about relevance to industry. “How much should we teach things of immediate use to industry, vs. how much should we lay the groundwork for lifelong learning? We can’t predict what skills will be required down the road.”

Ms. Schmidt suggested a balance. “We could be bringing back recent alums to talk about their experiences. We can’t predict what we’ll need years away, so we need a combination. Professors themselves can’t always be expected to know an extensive amount about applications, so we could bring in other people who do.”

Dr. Carter said she thought industry would be interested in talking to everyone as they try to figure out what skills they will need in five years. She had found industry people “really excited to be asked.”

Prof. Gross said he believed in letting students follow their own approaches. “Most undergrad curriculum is very structured. I encourage people to think about projects within each course, even a whole class project.”

Prof. Ando said that he brings back lots of alums from different levels to learn more from them, especially about non-academic careers for PhD students. “PhDs are great at lifelong learning. What we need to encourage is the ability to collaborate and communicate; evidence they can work on something other than their thesis.”

Prof. Green recalled taking a course on Dante, when he read the Divine Comedy. From this he learned a much more general skill – how to understand a different historical period and its literature. “These are lifelong skills. Learning how to model is similar. It involves experience with finding math that fits a real-world situation, dealing with problems that are not precisely formulated, and coming up with a reasonable solution in a fixed period of time.”

Sheldon Axler, dean of the College of Science and Engineering at San Francisco State University, said that when he had consulted engineers or biologists about what math they wanted, he got “a huge list of topics. This was gratifying, but unrealistic. The math would have been a mile wide and an inch deep. How did Illinois deal with that?”

Prof. Ando replied that the engineers hadn’t been quite that systematic, and were still working on their list, while the biologists had thought a lot about theirs. The mathematicians have an important role as advisors, he said. “We’ve taught a lot of math, and we have a realistic idea of what is reasonable to cover in a 13-week semester. I’m always trying to reduce their topics. They don’t believe me at first, so an important role for us is prioritization. These are students who are already taking five courses at a time for 15 weeks. The engineering curriculum is from the 19th century. There’s a tradition of taking an insane amount of material.”

Prof. Gross said that the *Bio 2010* report had a description of wonderful math topics that was “totally ridiculous for undergrads who were doing other things, too. In biology, the number one request from faculty is to teach students to read and interpret graphs. We don’t do that in calculus.”

Prof. Treisman, of the University of Texas and TPSE, said in his nine years as president of the Consortium for Mathematics and Its Applications (COMAP), he had found that only a few

students could find the mathematics to solve problems, which took different skills than those required to learn math in courses. “There was an unnatural suppression of math in these service courses,” he said. “That has changed in Research 1 universities. When I look now at the social sciences sector I see lots of math being taught. This is not true in community colleges, so we have the transfer student issue and the equity issue. A disproportionate percentage of students coming in are poor. We need resources for faculty to learn this stuff. ATE [Advanced Technological Education] is a beautiful project – learning how to learn what math students need, in context. It takes time to learn to teach in this way.”

Prof. Gross added that the new NSF project called QUBES, or Quantitative Undergraduate Biology Education and Synthesis, is designed to help faculty network across institutes in both upper and lower division biology. “So the NSF has realized the need for this,” he said.

Panel 2: How Math-Ed Research Can Improve Post-Secondary Math Education

Joan Ferrini-Mundy, Chair

Assistant Director, Education and Human Resources, National Science Foundation

Dr. Ferrini-Mundy called her specialty in mathematics education “a very specific part of what is a very broad agenda. We are interested in improving undergraduate math learning at scale. A big piece of the question is how to get it started more broadly.”

Among the primary needs, she said, are willing faculty, skilled faculty, institutional support, and changes in reward and recognition.

“We also need systematically developed knowledge from education research,” she said. This research should help:

- Answer questions that matter for practitioners
- Provide robust, accumulated knowledge that can be trusted to guide practice
- Help understand what instructional materials, learning objects, programs, curricula, and teaching approaches “work” – for whom, under what conditions, and, sometimes, why
- Enable policy makers, higher education administrators, and funders to be strategic in setting priorities and making investments

She added several key questions for the audience, starting with those of her co-panelists:

“How can research lead to improved teaching and learning of mathematics? What are the gaps?”

“How does a mathematician become a more effective teacher? What are the barriers?”

And all three panelists jointly posed the following:

- What do you wish you understood better about undergraduate mathematics learning?
- What tools and resources would help more mathematics faculty begin to move toward “active learning” approaches? How do we get results from research into the hands of faculty?

As an overall point, she noted the title of a meta-analysis published in *PNAS* – “Active learning increases student performance in the sciences, engineering, and mathematics,” and another in *Science*. “Serious journals are publishing important findings,” she said, adding that “EHR has ways to fund this kind of work.”

Karen Marrongelle

Interim Dean, College of Liberal Arts and Sciences, Portland State University

Dr. Marrongelle began by saying that the literature base for math education was now about three decades old, and is being augmented by the *International Journal of Research in Undergraduate Education*, launching in 2015.²

She explained the need for mathematics education research by offering a list of questions often posed by faculty: What can research tell us about class size? Do flipped classrooms work? How can we best teach students who don’t speak English? Should we use a placement exam? How should we prepare TAs to teach?

She said that it takes many strategies to answer questions such as these, including:

- Inquiry in classroom settings
- Empirical investigation
- Building and testing theory (from psychology and other fields)
- Developing and testing interventions
- Replicating results
- Understanding institutional contexts
- Coordination of research efforts
- Time and money

She said that research in undergraduate mathematics education (RUME) had evolved in the following sequence:

- (1) identifying student difficulties and cognitive obstacles
- (2) understanding the processes by which students learn particular concepts
- (3) classroom studies (including innovations)
- (4) research on teachers’ knowledge, beliefs, and practices

² Prof. Marrongelle is editor-in-chief of the new journal.

(www.springer.com/education+%26+language/mathematics+education/journal/40753)

She used the topic of limits to examine (1) above. She said that that students tend to draw upon ideas and intuitions from personal experience when trying to make sense of limit. For them, approaching means getting closer, but not necessarily arriving, so that limit means a boundary that is not crossed. Students also have over-reliance on a dynamic view of limit, such that no term in a convergent sequence can be closer to the limit than the previous term.

Under (2), students' beliefs about limit (e.g., a boundary that cannot be crossed) are resilient, even in the face of counter-examples.

Under (3), classroom studies show that students rely on different metaphors for limit throughout calculus – e.g., approximation – and they can re-invent the formal definition of limit by explicitly focusing on a “y-first” approach.

Under (4), research has found that “students and teachers often talk past each other when discussing limit.”

“This research has profound implications for what we may be doing in our classrooms,” she said, although there are still gaps in understanding:

- What does a student's understanding of limit predict about her success in calculus?
- How can a pre-calculus curriculum be designed to more effectively support learning limits in calculus?
- Could approximations be used in place of limit in the calculus curriculum?
- What *pedagogical content knowledge* do instructors need to help students navigate the complex idea of limit?

She cited some characteristics of successful college calculus programs derived from a large-scale study at 2- and 4-year institutions. Each had five pedagogical activities that were significantly related to students' decisions to continue to Calculus II after Calculus I:

- (1) examples of worked problems
- (2) extra material prepared for students
- (3) whole-class discussions
- (4) explanations required for thinking on exams
- (5) explanations required during class

Significant remaining challenges, she concluded, include textbooks that do not reflect the knowledge base on teaching and learning; RUME research with larger data sets; better ways to disseminate results; and the need to know how post-secondary research affects student retention.

Prof. Treisman commented that “advising needs major work,” and that “too much choice leads to paralysis.”

Chad Topaz

Associate Professor of Mathematics, Macalester College

Prof. Topaz began by saying he was not a math education researcher and would speak “as a practitioner.” But he noted a “depressing side to the topic of the panel: What are the barriers? Why isn’t the research put into practice?”

He turned the question around to ask, Why would research be used? “You have to believe that pedagogy is real, a thing. Teachers need to get results, understand them, then decide to change their teaching. This takes resources, and you have to persist.”

He offered a series of ideas on how to overcome some of these barriers. “The first thing to do,” he said, “is to legitimize pedagogy. I was never taught anything about it. I believed the pouring-water-into-a-glass model of educating. You just present the knowledge.” He recommended a report from the National Research Council called *How People Learn*, which has “synthesized all the research.”³

He said that he relied heavily on the design of learning environments, which had to have four qualities: “They must be knowledge centered,” which he said was the traditional approach; “learner centered (paying attention to what students need); assessment centered (frequent opportunities for formative experiences, with feedback); and community centered (I try to treat every class that way). We have to convince people that this is real.”

Idea two, he said, was to translate the basic research. This was a way of reducing the “antagonism between achievement and enjoyment.”

Idea three was to promote the sharing of models, ideas, and resources by means of the flipped classroom. “Students prepare for class before the class. In class they apply key concepts and get feedback from peers and myself. There are already many good models on YouTube.”

Idea four was to “lower the activation energy. It’s hard for teachers to get started. It seems like an insurmountable task. They might need time, labor, technology, tech support, classroom spaces, expert pedagogy support, financial support.”

Idea five is to expect change to be gradual. “Teach the same course recurrently. Change one thing at a time. Teaching is a skill you learn through practice.”

Idea six is to align incentives with priorities. He recommended a new report from the National Academies, *Reaching Students*,⁴ and said that higher education still values research more highly

³ National Research Council (2002), *How People Learn: Brain, Mind Experience, and School*, National Academies Press, Washington DC. (www.nap.edu/openbook.php?isbn=0309070368)

⁴ NRC (2015), *Reaching Students: What Research Says About Effective Instruction in Undergraduate Science and Engineering*, National Academies Press, Washington DC. (www.nap.edu/catalog/18687/reaching-students-what-research-says-about-effective-instruction-in-undergraduate)

than teaching. “Publications are the strongest predictor of faculty pay. If we really think this matters we should work for change. Tell everyone: The incentive structure has to change. Students do what they’re assessed on; so do we.”

Discussion

Dr. Axler commented that the reward system did not necessarily weaken teaching. “On average,” he said, “our best teachers are also our best researchers.”

Prof. Treisman reiterated the size of the challenge in teaching students to transfer skills and knowledge from one situation to another. “That is the holy grail of social and developmental psychology. It’s a gigantic mess. Recent breakthroughs are being tested, but little is known about teaching for transfer, and we’re struggling.”⁵

Prof. Ferrini-Mundy commented on the 2008 report of the National Mathematics Advisory Panel on K-8 math. “We looked at what research there was,” she said, “examining whether teaching math in real-world contexts led to an ability to apply it. But we had little to say in terms of positive results. It seems logical but we don’t understand it.”

Prof. Shlyakhtenko asked about including application questions in crossover courses, especially math biology or math physics. “If I do it honestly,” he said, “and create a meaningful example for biology, it’s complex, and not a crisp example for math. So should one use an example that’s clear on the math but biologically irrelevant?”

Prof. Ferrini-Mundy said it might be useful to think of a novice-to-expert progression of learning, which is discussed in physics and cognitive science. “Think of our students as novices, ourselves as experts. A fair amount of research has been done on progressions in grades K-8.” In response to a request for help for those who have been teaching math in traditional ways for many years, she suggested trying “to find a window into the student’s thinking – either through assessment tools or through interviews.”

Prof. Treisman emphasized the difficulty of teaching in general. “Here’s the problem,” he said. “Teaching is a complex diagram to make real in the classroom. How do you learn to actually listen to the student? While you’re doing that, the rest of the class falls apart. It’s a real skill. There are some nice pieces about how to do it, but it’s much harder than people think.” He recommended the NRC publication *Adding It Up*.⁶

David Levermore said that he often teaches differential equations, and has found that when he asks a final exam question a certain way, he sees that even after a whole semester, most

⁵ Prof. Treisman recommended the following paper: Daniel L. Schwartz & John D. Bransford (2001), “Rethinking transfer: A simple proposal with multiple implications,” *Review of Research in Education*, 24, 61-101.

⁶ NRC (2001), *Adding It Up*, National Academies Press, Washington DC. (<http://www.nap.edu/catalog/9822/adding-it-up-helping-children-learn-mathematics>) “These books are beautiful,” said Prof. Treisman. “They were very hard to put together. People argued.”

students hadn't learned what an initial value problem was. He had decided to just have them do it in words.

Eric Kostelich of Arizona State University commented that challenges are even more difficult at other post-secondary institutions, few of which have students at the level of Macalester's. Prof. Marrongelle said she shared this concern. "My institution [Portland State University] serves many returning veterans, and 80% of our entering students are community college transfers. You're right that you have to understand the context in which students learn. Some just have to be treated differently."

Prof. Friedlander asked if any research had compared how acquisition of skills varies – why some students are good in algebra, for example, and others in applications. Prof. Ferrini-Mundy described a metric called Aptitude Treatment Interaction that measures people with high skills in certain areas. Spatially oriented students could benefit from more visual teaching techniques, for example. Prof. Treisman said this idea had been explored in psychology for decades without finding single keys to learning. "People need a combination of skills," he said. "We need to broadly educate students rather than trying to guess which skill they have and teach narrowly to that." Prof. Topaz added that the word aptitude is not used as much today. "It's not supported that some people are math people and some are not. It's better to foster the mindset that if you work hard you can keep going."

Panel 3: System-Wide Efforts to Improve Post-Secondary Math Education

Uri Treisman, Chair

Professor of Mathematics and of Public Affairs; Executive Director, Charles A. Dana Center,
The University of Texas at Austin
TPSE Math

Prof. Treisman opened the panel by noting that earlier panels were concerned with learning from successful efforts at improving post-secondary math education, especially for low-income and minority students. He described finding broad commonalities in many of the successful programs that were examined. Unlike programs housed in the administration, the successful programs focused on students' assets rather than their deficiencies, and provided participating students with a community of peers with whom they could learn and normalize their understanding of what was expected of them.

These communities were organized with a commitment to and an affection for mathematics. Professor Treisman referred to these efforts as "acculturative mechanisms" (i.e., effective introductions to the community of mathematicians). He went on to say that many of these efforts were led by a small group of faculty in a math department, and that when these faculty members retired, the programs often disappeared. Fortunately, he said, "there are powerful exceptions with links to other departments and institutions, including the University of Illinois at Urbana-Champaign, Statway and Quantway, and the California Acceleration Network. At least a dozen states are trying to learn from the reform work in Ohio."

Karon Klipple

Executive Director, Community College Pathways Program,
Carnegie Foundation for the Advancement of Teaching

Dr. Klipple opened by saying that the purpose of Statway and Quantway is to “prepare our students for their degrees and careers” and to “learn meaningful mathematics skills and strategies.” She said that the programs began when Prof. Treisman and Tony Bryk, president of the Carnegie Foundation for the Advancement of Teaching, had an idea for an alternative approach, working together with college and university faculty.

The problem, she said, was that in community colleges, which educate almost half the students in the country, 60 to 80% of students are placed in developmental math. Of those, only 20% complete that course and one college-level math course.

“I was teaching statistics, and I was invited to try Statway, and fell in love with it,” she said, adding that the pathways approach had several central elements:

- Structural Change: accelerated cohort experience, reducing time and transitions; college-level mathematics with developmental math supports; maintains rigor and meets pre-college math requirements
- Pedagogical and Content Shift: math is taught in authentic contexts, and aligned with specific programs of study; learning is active and collaborative
- Integrated Student Supports: the institution provides student and faculty resources to address non-cognitive factors and language/literacy barriers
- Network Improvement Community: space for shared learning with a common curriculum, pedagogy, and assessments; evidence base for continuous improvement

To guide this ambitious agenda, Carnegie formed a network of community colleges, professional associations, and educational researchers. Rather than a seemingly random walk through a maze of course options, students and faculty join in a coherent, intensive year-long experience to achieve college math credit in one year. Statistics (Statway) and Quantitative Literacy (Quantway) bring the core college-level content, while developmental learning goals are integrated throughout. A key to this experiment, she said, is that it enables a community – of faculty, administrators, and institutional researchers – to engage in systemic change.

Since it began in 2011, success has been measured by the percentage of students who earn a C or better in their traditional college sequence. In its first three years, the program has been scaled up to double the number of faculty, students, and institutions; there are now 50 participating institutions in 15 states. About half of Statway’s students have succeeded in the three years of scaling up the program, while only 15 percent of the comparison, non-Statway groups have succeeded. This success is seen at every institution where it is implemented.

This success is also observed in all subgroups of gender and race/ethnicity. For example, among the white female subgroup, 61% of Statway students succeeded, vs. 15% of non-Statway

students. Among Hispanic male students, 42% in the Statway group succeeded, vs. 8% in the non-Statway group. Among black male students, 47% in the Statway group succeeded vs. 7% in the non-Statway group. In addition, students in both pathways accumulate more credits (C or better) in the year following completion than students in comparison groups.

Similarly, students in Quantway who went through the development course did as well as those who didn't have to start at that level. And faculty in the Statway program performed better than they had in the traditional system.

The program also studied students' beliefs and attitudes, finding marked shifts. For example, within three weeks of beginning the program some students who had "hated" or feared mathematics now described a sense of confidence, and/or actually enjoyed it.

Myra Snell

Professor of Mathematics, Los Medanos College

Prof. Snell related her experiences in teaching in a California program similar in principle to Statway. A pivotal point in piquing her interest in innovative programs was an experience in a community college team that received a five-year Title III grant to reform the algebra curriculum. "I was so proud of my department," she recalled. "Every instructor came to our faculty meetings every week, we all worked hard, we met all our grant goals. The main goal was to increase the core success rate by 10% and maintain it over life of the grant, which we did. I was proud of our work."

At end of the grant, however, she was shocked to learn that only 17% of the students actually made it through a transfer level course in three years. "We were looking at only the core success rate, and the metric we should have been looking at was completion. This was devastating to me. But it made me understand that now I'd have to focus on completion."

She had further realizations about the structure of community college teaching. One is the requirement for new community college students to study elementary algebra. She realized that each of these students has about five "exit points" where only about 70% of them are retained. First they must pass the elementary course; second, they must choose to enter intermediate algebra; third, they must pass intermediate algebra; and so on. "And I thought, if we have a 70% core success rate at each point, what we really have is that 70% success rate repeated five times, which is a success rate of 17%. That is a big deal."

Another realization was that only about 20 to 30% of community college students in California were STEM majors (she learned later this is true nationwide). "So we had to think about what the students really want to study, and what to do if it's not mathematics."

Finally, she thought about the alignment between the developmental sequence used by community colleges and the courses students actually take to meet their lower division transfer

requirement. That course tends to be statistics, and she saw that there was little in what the students took at entry level that prepared them for statistics.

“Where these realizations lead us to is a place like Statway. This is rigorous math work. It does not take the ‘deficit approach’ with students. It doesn’t say, let’s look back and see what you don’t remember from high school or middle school, and let’s put you through that curriculum again. Instead, it looks forward: We know what the college courses look like, now let’s prepare you for that. Let’s make the preparation short, but well aligned to what you’re going to be studying.”

After her experience working with Statway, she co-founded the California Acceleration Program with a friend who teaches English. “But we are really focused on Statway,” she said. “The data I’m going to share with you is essentially Statway data.” She said the programs have similar design components, and respond to similar problems.

“The problem we’re trying to solve,” she said, “is that large numbers of students are coming into math remediation. This a problem for mathematics, and it has a large equity component. In California, more than half of black and Latino students place 3 or 4 levels below the average in math. So they go to a remedial track of pre-algebra or arithmetic. But only 6% of students placed at that level ever go on to complete a college-level math course. It’s a form of institutional racism – a structural component that is guaranteeing that these students are not going to succeed.”

In the California Acceleration Program, which has little funding, she worked with math faculty to design a one-semester remedial course that prepares students for statistics. “First, we tell them not to change their existing course, but we show them a set of design principles. The 23 colleges I work with design backwards from the post-secondary statistics class.

“Second, we design a thinking-oriented curriculum. Most math instruction is not really mathematical thinking; it tends to be around mimicry, and matching procedural skills. Third, we use just-in-time remediation. We design the course so students don’t come in and say, Oh no, fractions! I can’t do fractions. Instead they see an interesting problem that may involve a contingency table. Are we going to use some fractions and compare ratios and build conditional probabilities? Yes, but it’s all contextualized, and more interesting for them. Then we do some remediation around that, but it’s just-in-time remediation; not a whole semester. And it’s pulled along by an interesting problem.

“Fourth, we pay attention to the affective domain – how students feel about what they’re doing. We talk about a fixed mind set: a way to name the behavior when someone begins to shut down, thinking it’s too hard. We teach that ‘You can grow your brain.’ That’s a real epiphany for students.

“And the last design principle is low-stakes collaborate practice. Students are interactive, and do important work with each other, but in a low-stakes way.”

Given these similarities with Statway, she said, what are the results? She hired the RP Group of Berkeley, a professional organization of institutional researchers, who looked at eight colleges she worked with. They did multivariate regressions, controlled for 13 covariates, looking at the same metrics Statway used. They found that a student's chance of completing a college-level course in statistics was 4.5 times higher than for students who went through traditional remediation. "Imagine a world where we increased student completion of college level math at that rate!" she said.

In addition, she said, the equity implications are large. For black students, the percentage moving ahead to complete a transfer-level math course rose from 7% to 49%. Also, the familiar achievement gap between black and Asian students was eliminated for members of the two groups placed in the California program instead of traditional remediation.

One of the challenges to scaling this kind of work, she said, was lack of professional development for teachers. She found that some community colleges have not been able to offer more pre-statistics courses than the two they are required to offer, so she spends a lot of time working with faculty on assessments and activities at different levels of cognitive demand. Another challenge, she said, is how to facilitate student learning without jumping in too soon. "As we all know, the minute we jump in, we undercut the opportunity for productive struggle. Sooner or later you'll lose them if they don't get to struggle and learn to solve their own problems."

Finally, she told the attendees from the California State University and the University of California systems that the biggest impediment to scaling her work in California is "your policies requiring intermediate algebra as a requirement to transfer. When you have a policy like that in place, all this innovation you guys are doing is cut off to us. If you have to get students through intermediate algebra, they have to face elementary, and pre-algebra, and arithmetic, and you're going to lose them. We're precluded from doing all this innovation we're hearing about at the university level. So let us figure out what we need to do to prepare students."

Prof. Treisman put in a closing word on the two pathways efforts. He said that about 56% of remedial students in the programs will have completed a college math course in one year, using principles that are broadly applicable. "This is dramatically, stunningly improving success rates," he said, "especially for African-Americans. I don't think I've ever seen anything like this in higher education."

Paula Compton

Associate Vice Chancellor, Ohio Board of Regents

The state of Ohio was relatively early in recognizing its institutional problems in post-secondary education and in deciding to address them in innovative ways. One of these strategies, decided by the state Board of Regents, was to empower faculty members – rather than state officials –

to tackle the issues themselves. Dr. Compton has been a key figure in this process, which began only two years ago and has already produced promising results.

The University System of Ohio began the process in May 2013 by calling a Mathematics Summit of 150 faculty members representing the 36 public institutions of higher education. The purpose of the meeting was to discuss a number of policies that were restricting the ability of institutions to modify teaching and learning structures. The keynote speaker was Uri Treisman of the University of Texas at Austin and TPSE Math, who had already been experimenting with new pathways for math students, especially those transferring from community colleges to four-year institutions.

The main topics discussed were:

- Persistence issues related to mathematics
- Transfer issues regarding Ohio Transfer Module (OTM) mathematics, statistics, and logic guidelines
- Effective quantitative pathways for STEM and non-STEM majors
- Uniform statewide standards for remediation-free status and Ohio college readiness expectations

The meeting generated much excitement, and an Ohio Higher Education Mathematics Steering Committee consisting of 11 mathematics faculty members, five ex-officio members, and the chair Joan Leitzel, who had served as mathematics professor at Ohio State University for more than two decades, was formed in fall 2013.

The charge of the Steering Committee was “to develop expectations and processes that result in each campus offering pathways in mathematics that yield:

- Increased success for students in the study of mathematics,
- A higher percentage of students completing degree programs, and
- Effective transferability of credits for students moving from one institution to another.”

The Steering Committee continued under the chairmanship of Prof. Leitzel, and the Ohio Board of Regents provided financial support for meetings, logistics, and continued consulting by Uri Treisman and Jenna Cullinane of the Dana Center in Austin. In early 2014 Treisman and Cullinane produced a report that identified five key strategies to reach the goals of the charge. With additional support from a College America Grant and some Race for the Top funds from the State Department of Education, the newly formed Ohio Mathematics Chair Network in early June 2014 appointed five subgroups of 71 faculty members to address key issues. In fall 2014 these groups proposed five strategies for the state’s institutions:

1. Establish New and Alternative Pathways:
 - Align mathematics to academic programs of study

- Improve instructional delivery mechanisms
 - Develop, implement and evaluate co-requisite strategies to support underprepared students
2. Develop transfer policies and processes that foster effective transfer of course credits while encouraging innovation on all public campuses.
 3. Do communication, outreach, and engagement.
 4. Do data collection, analysis, and sharing.
 5. Improve alignment between secondary and postsecondary content and instruction.

Another significant result, she said, was the Ohio Mathematics Chair Network's decision to remove intermediate algebra as a prerequisite for the Ohio Transfer Module Mathematics Courses and to open the way to new alternative courses that would be part of the state pathways. It did so by issuing an official definition of a college-level course: "A credit-bearing, college-level course in mathematics must use the standards required for high school graduation by the State of Ohio as a basis and must do at least one of the following: (1) broaden, (2) deepen, or (3) extend the student's learning." This definition also means that college courses cannot simply repeat what is taught in high school. "It doesn't mean that we don't believe in prerequisites," said Dr. Compton. "It means that the institutions can decide, not the state."

Scott Waugh, provost of UCLA, offered closing words, thanking the participants for their contributions to the symposium and for their work on behalf of post-secondary mathematics education, and expressing enthusiasm for UCLA's involvement in this important project as it develops.