

## Department of Mathematics

The faculty in the [Department of Mathematics](#) are unique in their world leadership in many central fields in pure and applied mathematics, with specialists in analysis, geometry, topology, algebra, number theory, physical applied mathematics, computational science, computational biology, theoretical computer science (including quantum computing, optimization, machine learning, and computational complexity), combinatorics, probability, and statistics. As such, we interact with researchers in many other MIT departments and centers, including Electrical Engineering and Computer Science, Biology, Physics, Mechanical Engineering, and Civil and Environmental Engineering, as well as the Institute for Data, Systems, and Society; the Broad Institute; and increasingly the MIT Stephen A. Schwarzman College of Computing.

In AY2020, the Department of Mathematics had to suddenly face the many challenges of the Covid-19 pandemic and quickly move to remote learning in mid-March. The department's faculty, lecturers, postdocs, and administrators were fully engaged in adapting to online teaching to complete the spring term and creating a much more stable platform for instruction for the beginning of the fall 2020 term. As a world-class leader in mathematical research, education, and outreach, the Mathematics Department is especially committed to maintaining the very highest standards in each of these mission areas.

Institute leadership has been especially focused on increasing awareness of systemic institutional racism and prejudice in academia and diversifying its student bodies, faculty, postdoctoral staff, and support staff. The department participated in public forums provided by the Institute and School of Science and also developed its own community efforts for AY2021. The department's Diversity and Community Building Committee continued to review initiatives and design new ones to include the larger undergraduate body in the mathematical livelihood of the department.

### Faculty

#### New Joint Faculty Member

Professor Pablo Parrilo (Electrical Engineering and Computer Science) joined the mathematics faculty in a joint appointment in AY2019. Parrilo has conducted research with mathematics faculty, taught subjects in the Mathematics with Computer Science program, and been an invaluable colleague in department decisions. He is also very involved in Common Ground, an MIT Schwarzman College of Computing educational initiative designed to provide courses across the Institute dealing with computation. He has served on the science advisory board of the University of California at Los Angeles (UCLA) Institute for Pure and Applied Mathematics and the advisory panel of the Society for Industrial and Applied Mathematics (SIAM) Activity Group on Algebraic Geometry, among other outside professional activities.

#### Faculty Changes

Larry Guth was appointed the Claude E. Shannon Professor of Mathematics as of July 1, 2019.

Bjorn Poonen was appointed the Distinguished Professor in Science. He is the inaugural holder of this faculty chair awarded by the School of Science.

David A. Vogan retired from the mathematics faculty as Norbert Wiener Professor of Mathematics in June 2020. He received his PhD from MIT under Bertram Kostant and joined the MIT faculty in 1979. He worked on unitary representations of Lie groups, the continuous symmetries arising in subjects from quantum physics to number theory. In addition, he collaborated with many colleagues on the Atlas of Lie Groups and Representations (software for studying representation theory). Current understanding of unitary representations is largely due to his insights.

A mentor of 32 doctoral students, Vogan served as chair of the Undergraduate Committee for three terms and as chair of the Graduate Committee for two terms. He chaired the Pure Mathematics Committee during 1997 to 1999 before serving as department head from 1999 to 2004. He was president of the American Mathematical Society from 2013 to 2015. A former Sloan Research Fellow, Vogan was selected by the department faculty as the Robert E. Collins Distinguished Scholar (2007–2012). He was a fellow of the American Academy of Arts and Sciences (1996) and a member of the National Academy of Sciences (2013). In 2014, he was selected to be the Norbert Wiener Professor of Mathematics.

Laurent Demanet was promoted to full professor.

Associate Professors Semyon Dyatlov and Ankur Moitra each received tenure.

Assistant Professor Vadim Gorin resigned from MIT for a faculty appointment at the University of Wisconsin, Madison.

Assistant Professor Aaron Pixton resigned from MIT for a faculty appointment at the University of Michigan.

Assistant Professor Giulia Saccà resigned from MIT for a faculty appointment at Columbia University.

### **In Memoriam**

The Department of Mathematics lost two of its emeritus faculty in AY2020.

Gerald Enoch Sacks, professor emeritus of mathematical logic at MIT and Harvard, died at his home in Falmouth, ME, on October 4, 2019, at the age of 86. Professor Sacks joined the MIT mathematics faculty as a professor in 1967 (his title was changed to professor of mathematical logic in 1971) following several years at Cornell University.

Professor Sacks' mathematical interests were broadly distributed across mathematical logic, and he made fundamental contributions to computability theory, set theory, and model theory. For him, mathematical logic was about definability: its essential nature, its hidden structure, and its extent and limitations.

Sacks' collaboration with Georg Kriesel shifted his attention permanently from definability as computability to an effort to understand the common structure of relative definability. He found some of the first connections between set theoretic structure and definability theoretic characteristics. His "Plus-One Theorem" connected S. C. Kleene's recursion in finite types to admissible set theory, and his "Least-Admissible Theorem" connected countable admissible ordinals to relative computability. He derived "Sacks Forcing," now a standard device in axiomatic set theory.

In 1973, Sacks received a rare joint professorship appointment between MIT's and Harvard's mathematics faculty. This accommodated further developments in mathematical logic, particularly in the area of recursion theory, a precursor of today's computer science. He authored three books and monographs: *Degrees of Unsolvability* (1963), *Saturated Model Theory* (1972), and *Higher Recursion Theory* (1990). He also published *Mathematical Logic in the 20th Century* (2003), a collection of influential papers by other leading mathematical logicians.

Throughout his academic career, Sacks was a major doctoral advisor, producing future leaders in the field and graduating 31 PhD students. In 1994, Sacks' former students and colleagues created the Sacks Prize in honor of his research contributions and his excellence in graduate advising. The prize continues to be awarded annually for the most outstanding doctoral dissertation in mathematical logic, now under the auspices of the Association for Symbolic Logic. Sacks retired from MIT in 2006 and from Harvard in 2012.

Sacks was a Guggenheim Fellow in 1966–1967 and a Fulbright-Hayes Scholar in 1979. He was an invited speaker at the 1970 International Congress of Mathematicians (ICM) and chaired the selection committee on mathematical logic for the 1978 ICM. He also gave invited addresses at the International Congress of Logic, Methodology and Philosophy of Science in Bucharest (1971) and London (1973). To commemorate Sacks' 60th birthday, the MIT Mathematics Department hosted a four-day Sacks Symposium in May 1993.

Richard Mansfield Dudley, professor emeritus of mathematics, died on January 19, 2020, following a long illness. He was 81. He is credited for fundamental breakthroughs in the theory of stochastic process and the general theory of weak convergence.

Professor Dudley joined the MIT mathematics faculty in 1967 following instructor and junior faculty appointments at the University of California at Berkeley (1962–1967). Starting in the 1960s, Dudley shaped the fields of probability, mathematical statistics, and machine learning, with highly influential contributions to the theory of Gaussian processes and empirical processes. What is now widely known as "Dudley's entropy bound" has become a standard tool of modern research in probability, statistics, and machine learning. Dudley's work also had a transformative impact on the theory of empirical processes initiated by Vladimir Vapnik and Alexey Chervonenkis in the context of machine learning.

Over a series of papers, starting with his landmark "Central Limit Theorems for Empirical Processes" (published in 1978 in the *Annals of Probability*) and culminating with his influential 1984 Saint-Flour lecture notes (and, later, his book *Uniform Central Limit Theorems*, published by Cambridge University Press in 1999), Dudley distilled

and developed these ideas into an actionable theory that today remains the reference framework in mathematical statistics and statistical learning theory.

Dudley gave a number of distinguished research talks. He was an invited speaker at the 1974 International Congress of Mathematicians as well as at meetings of the American Mathematical Society, the Institute of Mathematical Statistics, and the Bernoulli Society. He was also an invited lecturer at the Saint-Flour summer school in probability and several Vilnius Conferences on Probability Theory and Mathematical Statistics. He was a regular participant in and organizer of several conferences and meetings, including Probability in Banach Spaces.

In 1976, Dudley visited the University of Aarhus and there produced a set of graduate lecture notes, “Probabilities and Metrics.” These notes were to become a part of his graduate text *Real Analysis and Probability* (published by Wadsworth in 1989). The text has since become a standard, and in 2002 it was reissued by Cambridge University Press. He advised 33 PhD candidates (32 at MIT), producing some 110 academic descendants.

Dudley served the scholarly community as associate editor (1972–1978) and then chief editor (1979–1981) of *Annals of Probability*. He was a member of the editorial board of the Wadsworth/Brooks/Cole Advanced Series in Statistics/Probability from 1982 to 1992. He retired from the MIT faculty in 2015.

Among his honors, Dudley was an Alfred P. Sloan Research Fellow (1966–1968) and a Guggenheim Foundation Fellow (1991). He was selected to serve on the honorary Advisory Board of Stochastic Processes and Their Applications from 1987 to 2001. In 1993, Dudley was elected a fellow of the American Statistical Association “for world-recognized contributions to probability theory with far-reaching consequences for statistics, for founding the modern theory of empirical processes, and for dedication to many successful PhD students.” He was also a fellow of the Institute of Mathematical Statistics, the American Association for the Advancement of Science, and the American Mathematical Society and a member of the International Statistical Institute.

### **Faculty Awards and Honors**

The Mathematics Department and its faculty were honored with a number of major distinctions.

The Department of Mathematics received the 2020 American Mathematical Society Award for an Exemplary Program or Achievement in a Mathematics Department for its Program for Research in Mathematics, Engineering, and Science (PRIMES), which targets high school students. This award recognizes a department that has distinguished itself by undertaking an unusual or particularly effective program of value to the mathematics community, internally or in relation to the rest of society. MIT PRIMES was founded by Professor Pavel Etingof and Lecturer Slava Gerovitch. By June 2020, 509 students had participated in PRIMES and PRIMES-USA, 103 had completed the PRIMES Circle program, and 120 had participated in the summer MathROOTS program (the newest addition to the PRIMES program). After finishing the program, 125 PRIMES alumni and 37 MathROOTS alumni matriculated at MIT.

The department also received an American Mathematical Society Epsilon Award for Young Scholars Programs for the MathROOTS program. The award provides support for summer programs aimed at mathematically talented high school students.

Professor Bonnie Berger was elected a member of the National Academy of Sciences. She was also selected to give the Association for Women in Mathematics/Society for Industrial and Applied Mathematics Sonia Kovalevsky Lecture at the 2020 SIAM annual meeting. The aim of this lecture is to highlight significant contributions of women to applied or computational mathematics.

Professors Alexei Borodin and Zhiwei Yun were each selected for a 2020 Simons Investigator Award in Mathematics. This award is given to outstanding theoretical scientists to support long-term investigations of fundamental questions.

Professor Borodin was also awarded the 2019 Fermat Prize for the invention of integrable probability theory, a new area at the interface of representation theory, combinatorics, and statistical physics. In addition, he received the 2020 Bernoulli Prize for an outstanding survey article in probability (jointly with Leonid Petrov at the University of Virginia). The article was titled “Integrable Probability: From Representation Theory to Macdonald Processes.”

Professor Alan Edelman received the 2019 Institute of Electrical and Electronics Engineers Computer Society Sidney Fernbach Award “for outstanding breakthroughs in high performance computing, linear algebra, and computational science and for contributions to the Julia programming language.” The award recognizes outstanding contributions in the application of high-performance computers using innovative approaches.

Professor Emeritus Daniel Z. Freedman was awarded the Special Breakthrough Prize in Fundamental Physics jointly with two colleagues, Sergio Ferrara of CERN and Peter van Nieuwenhuizen of Stony Brook University, with whom he developed the theory of supergravity.

Professor Larry Guth received the newly named Maryam Mirzakhani Prize in Mathematics (formerly the National Academy of Sciences Award in Mathematics) “for developing surprising, original, and deep connections between geometry, analysis, topology, and combinatorics, which have led to the solution of, or major advances on, many outstanding problems in these fields.” The Mirzakhani Prize honors exceptional contributions to the mathematical sciences by a mid-career mathematician. He was also awarded the 2020 Bôcher Memorial Prize by the American Mathematical Society for his “deep and influential development of algebraic and topological methods for partitioning the Euclidean space and multiscale organization of data, and his powerful applications of these tools in harmonic analysis, incidence geometry, analytic number theory, and partial differential equations.”

Assistant Professor Peter Hintz received a Sloan Research Fellowship.

Professor Victor Kac was elected a member of the Accademia Nazionale dei Lincei, one of the oldest scientific academies in the world.

Professor Ju-Lee Kim received the MIT Earll M. Murman Award for Excellence in Undergraduate Advising, “presented to a faculty member who has served as an excellent advisor and mentor for undergraduates and who has had a significant impact on their personal lives and academic success.” Kim was also recognized for expanding her services as co-chair of the mathematics major advisor’s committee to make the major more inclusive and supportive.

Professor Elchanan Mossel was selected for a Vannevar Bush Faculty Fellowship by the Department of Defense for his research on information flows on networks.

Professor Peter Shor was elected a member of the National Academy of Engineering for his pioneering contributions to quantum computation. Also, Professor Shor and colleagues Charles H. Bennett (IBM Research) and Gilles Brassard (University of Montreal) received the Banco Bilbao Vizcaya Argentaria Foundation Frontiers of Knowledge Award in the Basic Sciences category “for their fundamental role in the development of quantum computation and cryptology.” In addition, Shor received an inaugural Test of Time Award (jointly with Kenneth L. Clarkson) for an influential paper that appeared prior to 2000 in the *Proceedings of the Annual Symposium of Computational Geometry*.

Professor Gigliola Staffilani was honored with the Committed to Caring (C2C) Award by the MIT Office of Graduate Education. The C2C program recognizes outstanding mentors and promotes thoughtful, engaged mentorship throughout the Institute.

Professor Gilbert Strang was elected a foreign member of the Russian Academy of Sciences in the Applied Mathematics and Computer Science section. He also received the 2020 Irwin Sizer Award from the MIT Graduate Student Council for significant innovations in and improvements to MIT education.

Associate Professor Nike Sun was presented the 2020 Wolfgang Doeblin Prize, awarded biannually by the Bernoulli Society for Mathematical Statistics and Probability. The prize is given to a single individual who is at the beginning of her or his mathematical career for outstanding research in the field of probability.

Professor Chenyang Xu was selected for the 2020 Class of Fellows of the American Mathematical Society. He was recognized for “contributions to algebraic geometry, in particular the minimal model program and the K-stability of Fano varieties.”

Professor Wei Zhang received the 2019 Clay Research Award in recognition of his “ground-breaking work in arithmetic geometry and arithmetic aspects of automorphic forms.”

Assistant Professor Yufei Zhao received the 2020 MIT UROP Outstanding Mentor Award, presented to research mentors who have demonstrated exceptional guidance and teaching in a research setting.

The MIT research support committee selected two mathematics faculty members to receive support from the Charles E. Reed Faculty Initiatives Fund for AY2020: Assistant Professors Andrew Lawrie and Andrei Negut.

Research Scientist Edgar Costa was presented the 2020 Infinite Kilometer Award for his excellent mentorship of students engaged in Undergraduate Research Opportunities Program (UROP) projects and mathematics majors and for his contributions to the Simons Collaboration on Arithmetic Geometry, Number Theory, and Computation.

Lecturer Slava Gerovitch received the Infinite Mile Staff Award for his exemplary service as director and administrator of PRIMES and the department's research and reading programs for undergraduates.

CLE Moore Instructor Casey Rodriguez was selected for the 2020 Infinite Kilometer Award, which recognizes postdocs and research staff for exceptional contributions to their research program and to the community. Rodriguez is described as an outstanding junior colleague, an inspiring role model for math majors, a community builder for fellow postdocs, and someone fully engaged in the department's diversity mission.

### **Lectures**

The coronavirus postponed invited spring lectures throughout the mathematics community, which affected some of our faculty. Those who did give major talks are listed below.

Professor Berger delivered the keynote address at the International Society for Computational Biology Conference in Basel, Switzerland, in July 2019.

Professor Tobias Colding gave the spring 2020 Samuel Eilenberg Lectures at Columbia University.

Professor Mossel delivered the 2nd Annual Peter Whittle Lecture at Cambridge University in October 2019. That same month, he spoke at the 2nd Annual Joint Math-Stat Colloquium at the University of Oxford.

Professor Poonen spoke at the Brown University Distinguished Lecture Series and presented the Clay Lectures at the University of Arizona, both in March 2020.

Professor Paul Seidel presented at the Zabrodsky Lecture Series at Hebrew University of Jerusalem in December 2019.

Professor Staffilani gave the Rademacher Lectures at the University of Pennsylvania in December 2019.

### **Administration**

Michel Goemans completed his second year as department head and William Minicozzi his second year as associate department head. The senior faculty members who chaired the faculty committees listed below were the same as in AY2019.

Tobias Colding continued to chair the Pure Mathematics Committee and Peter Shor the Applied Mathematics Committee.

Davesh Maulik and Wei Zhang co-chaired the Graduate Committee in Pure Mathematics and Jonathan Kelner the Graduate Committee in Applied Mathematics. Ju-Lee Kim and Steven Johnson served as co-chairs of the Committee of Undergraduate Advisors.

Bjorn Poonen chaired the Faculty Nomination Committee and Alexei Borodin chaired the Moore Committee (for instructor hiring). Scott Sheffield continued as postdoc officer.

The department head's executive committee, which advises on issues arising in the department, consisted of Alexei Borodin, Pavel Etingof, William Minicozzi, Elchanan Mossel, Tomasz Mrowka, Paul Seidel, and Gigliola Staffilani.

## Development

The Department of Mathematics had another successful year in reaching out and engaging alumni and friends of the department. Prior to the pandemic, we continued to host events and faculty talks.

The department had a successful year in fundraising, particularly for the priorities of raising funds for a number of new graduate fellowships and increasing support for the MathROOTS program.

## Simons Lecture Series

The spring 2020 Simons Lectures were scheduled to be given by Bhargav Bhatt of the University of Michigan and Cynthia Dwork of Harvard University during the spring term. Due to Covid-19, these lectures were postponed to a future date.

## Conferences

- Representation Theory, Probability, and Symmetric Functions (August 22–24, 2019), organized by Professors Borodin and Gorin. The conference was held at MIT.
- Quantum Structures in Algebra and Geometry, Representation Theory, Probability, and Symmetric Functions (August 26–30, 2019), co-sponsored by MIT, Northeastern University, the National Science Foundation, and the Clay Mathematics Institute. Organizers were Professors Roman Bezrukavnikov (MIT), Maxim Braverman (Northeastern), Ivan Losev (Yale), Emanuele Macri (Northeastern), Davesh Maulik (MIT), and Valerio Toledano Laredo (Northeastern). The conference took place at Northeastern University.
- Charles River Lectures on Probability and Related Topics (October 4, 2019), organized by MIT professors Borodin, Mossel, Sun, Philippe Rigollet, Scott Sheffield, and Henry Cohn and Harvard professor Horng-Tzer Yau. The lectures were held in the MIT Wong Auditorium.
- Current Developments in Mathematics 2019 (November 22–23, 2019), jointly organized by the mathematics departments of Harvard University and MIT. The conference took place at the Harvard Science Center.



## Education

### Curriculum Updates

The undergraduate program in mathematics is doing extraordinarily well with a large number of majors—the third largest at MIT—and an unparalleled fraction of the strongest mathematics students worldwide. The undergraduate mission includes offering core, large-enrollment service subjects for the wider Institute and more advanced subjects for the mathematics major and those in related domains.

### Remote Learning: Response to Covid-19

In March 2020, the department was given the enormous challenge of making every class remote mid-semester. This was particularly an issue in large lecture classes, including the General Institute Requirements (GIRs), and in Communication Intensive classes. Many remote classes were conducted synchronously (in real time) via Zoom, while others were conducted asynchronously using several different technologies, including the automated lecture capture technology in rooms such as 2-190. Surveys of both faculty and students showed that the process was remarkably successful given the circumstances, but there were areas of concern. Perhaps the two largest issues were reductions in student engagements/interactions and the difficulty of remote assessment (especially in light of potential concerns about academic integrity).

Remote instruction will continue in the vast majority of mathematics classes in fall 2020. This will require significantly more resources in order to build and staff remote versions of the curriculum, with additional staffing needed to foster engagement and interaction. In preparation, the department has built remote Advanced Standing Exams (ASEs) for both calculus subjects, 18.01 and 18.02, using the MITx platform. In addition, the department has worked together with the Physics Department to prepare for a remote Mathematics Diagnostic Exam, also using MITx. Moreover, we have developed additional training for instructors, provided tablets to graduate students and instructors, and hired a large cohort of undergraduates to assist in remote instruction.

### The Service Core Curriculum

The Education Committee has several ongoing initiatives to revise the service core curriculum. These have been slowed but not stopped by the current pandemic. There are several factors driving change. Perhaps the greatest is the dramatic increase in demand at MIT for Course 6, especially for machine learning and artificial intelligence. This is particularly important in light of changes resulting from the creation of the MIT Schwarzman College of Computing. This places greater emphasis on linear algebra, probability and statistics, and discrete mathematics rather than on the continuous mathematics emphasized traditionally in physics and in many engineering disciplines. We have been working with other departments to ensure that our core subjects address the mathematics that their students need.

The GIRs are required of all MIT students. Roughly two thirds of students completely place out of 18.01 Calculus; the remaining third are split almost equally between 18.01 and 18.01A. Virtually all of the students in 18.01 have seen substantial amounts

of calculus before and are proficient with basic manipulations in calculus; generally, they are less strong in terms of pre-calculus skills (e.g., trigonometry, logarithms, and exponentials) and conceptual questions or word problems. Many peer institutions cover the 18.01 material in a full-year sequence (with the first semester corresponding to the Advanced Placement [AP] Calculus AB class). All of this creates substantial challenges for teaching 18.01 Calculus.

Professor Guth has been leading the redesign of 18.01 over the last year and will continue to do so in fall 2020, supported by both the department and alumni class funds. An important goal of the subject redesign is to base the subject on authentic problems, ones that ideally incorporate modeling of the world and involve multiple calculus topics or methods. This approach is task-centered instruction. The result will be a reorganized subject wherein each unit is based around an authentic problem. The problem will incorporate several calculus ideas already developed as well as one new calculus idea.

The Education Committee has also been rethinking the content in 18.02 Calculus (multivariable calculus). In the process, we have reached out to instructors of the largest downstream classes that use 18.02, such as the physics GIRs and subjects in unified engineering, machine learning, and differential equations. The 18.02 course is fast paced, and many peer institutions (e.g., Princeton and Columbia) have classes that cover similar material in two semesters; Stanford does so in two quarters in its math 50 series. We have been looking for ways to pare down the material and then add some material on vectors and matrices used by many downstream classes. This revision would have the benefit of moving material earlier that is currently duplicated in both 18.03 Differential Equations and 18.06 Linear Algebra, relieving pressure on a packed 18.03 curriculum.

Finally, we are coordinating with Course 6 on the design of the mathematical part of the Common Ground curriculum for the MIT Schwarzman College of Computing. The Common Ground is an interdepartmental teaching collaborative that will facilitate the offering of computing classes and computing-related curricula across academic units. Associate Professor Moitra will be working together with Professor Parrilo from Course 6 (joint with Course 18) on the design of a class that covers linear algebra along with optimization; the course will be part of the Common Ground for the new artificial intelligence and decision-making program. This is a growth area at MIT, and the class will likely serve a large audience. It is essential that the Mathematics Department be involved at these early stages to ensure that we are meeting the mathematical needs of the Institute.

### **Mathematics Diagnostic Exam**

In fall 2019, the department instituted a new procedure for giving credit for the 18.01 GIR through AP examination results. The procedure was formulated by the Education Committee in consultation with Course 8 and approved by the MIT Committee on the Undergraduate Program in April 2019. The new policy requires a top score on the AP Calculus BC exam together with a passing score on the Mathematics Diagnostic Exam (MDX), jointly administered by the Departments of Mathematics and Physics before the fall term. (The AP Calculus AB exam is comparable to the first half of 18.01 Calculus; the AP Calculus BC exam is the more advanced exam, comparable to all of 18.01.)

In the past, many students with AP BC credit did poorly in 18.02 Calculus. A good indicator of success in 18.02 was performance on the MDX administered by the Physics Department for placement in 8.01 Physics I (the first physics GIR); this diagnostic covered mostly pre-calculus. Accordingly, 18.01 AP BC credit now requires a validation score on a revised MDX that now also includes some basic calculus relevant to both math and physics. This new policy impacted 50 students who would have received 18.01 credit under the old system. These students still had the option to take the 18.01 Advanced Standing Exam, thereby proving their proficiency and obtaining 18.01 credit.

### **The Mathematics Major Breadth Requirement**

The Course 18 general major (the largest of several options) requires that students complete the service core of 18.01, 18.02, and 18.03 Differential Equations along with eight additional subjects (which must include a linear algebra class). Moreover, six of these eight subjects must be “advanced,” (i.e., they must have the first digit “1” or higher following the course number), and two must be Communication Intensive subjects. This makes Course 18 Mathematics one of the most flexible majors at MIT and a very attractive double major, especially since many of our classes are already required by other departments. However, the flexibility creates a risk that students could navigate the major in ways that either (1) do not expose them to as much abstraction and proof as majors should see or (2) focus on a relatively narrow subject area. We want to preserve flexibility while pushing students to experience breadth and depth in mathematics. To this end, we have approved a new “breadth requirement” that will apply to majors in the entering MIT class in the fall. Going forward, students will be required to take classes in at least three distinct areas; that is, the six advanced classes must include ones with at least three distinct first digits.

The very success of the major creates a challenge: addressing the broad range in student preparation. A good number of students, many of whom are active in the Putnam exam, arrive at MIT having already spent years thinking about higher level mathematics. Many of these students are immediately prepared for advanced classes and, in some cases, graduate classes. Conversely, the flexibility of the major attracts students who are much less advanced as well. This creates academic challenges, but perhaps more important it creates social challenges in building a community and can be intimidating for some students. The department has tried to mitigate these effects via social events, community building, and advising.

A number of our majors find the leap from the 18.0 courses to the advanced classes to be extremely challenging. At a rough level, the service core classes teach foundational mathematical skills, while advanced classes often focus on proof and have a completely different level of abstraction. Classes such as 18.100 Real Analysis, 18.200 Principles of Discrete Applied Mathematics, 18.650 Fundamentals of Statistics, 18.701 Algebra I, and 18.901 Introduction to Topology are simply at a different level than the service core subjects. We are taking a number of steps to help students bridge this gap. First, we offer four different versions of 18.100 at different levels of abstraction (and with or without a communications component). Second, we have introduced a new undergraduate geometry class, 18.900 Geometry and Topology in the Plane (developed by Professor Seidel at an intermediate level), that allows students to acclimate more gradually to

abstraction and proof. This class has been a success, earning strong student evaluations, and we are looking for similar opportunities in other subjects. Third, we have added recitations to 18.600 Probability and Random Variables and 18.650 Fundamentals of Statistics to ease the transition. Fourth, we are making tutoring available for gateway subjects in the major (18.100, 18.200, 18.600, 18.650, 18.700, 18.701, 18.702, 18.900, and 18.901) in the Math Learning Center. The center is open for several hours Monday through Thursday and has traditionally provided tutoring for service core subjects by capable undergraduates. The department has been experimenting with offering more advanced tutoring; this was popular with students. Finally, we will experiment this fall with adding undergraduate assistants to several of these gateway classes. These students will hold discussion/problem sessions that serve as optional recitations. We expect this to be a very popular program; the limiting factor is likely to be finding and recruiting enough undergraduate assistants.

### **MITx**

The subjects 18.01x Calculus (a series of three online modules) and 18.03x Differential Equations (a series of five online modules) are offered worldwide through the edX platform and have run successfully each year. The textbook for 18.03 now contains all of the interactive online materials developed and deployed on the MITx platform for our residential students. The on-campus subjects 18.01 Calculus, 18.01A Calculus (a six-week class offering a rapid review of single-variable calculus), and 18.03 Differential Equations collect a portion of the homework online through the MITx platform. The use of online homework allows students to receive immediate feedback and verify that they have the basic skills needed to solve the more involved paper homework.

The subject 18.02x Calculus is currently in development. With the support of an express grant from the Office for Digital Learning, the department has created a series of interactive three-dimensional images using Mathematica notebooks that explore tricky calculus concepts and ideas. These notebooks were used in lectures for the first time in spring 2019, with access for students to use them on their own. We have now received a full grant to build the interactive subject materials, which embeds these visualizations directly into the content as manipulatives that students can use to explore calculus concepts. We have also been developing problems that involve the themes of environment and sustainability. These problem designs are supported by a small grant from the MIT Environmental Solutions Initiative.

Part of the goal this year was to move the Advanced Standing Exams for 18.01 and 18.02 Calculus online to MITx. The original plan was to model our exams on the ASEs of biology subjects and of 6.0001 Introduction to Computer Science and Programming in Python, which have in-person proctoring of online exams using the MIT platform. The move to remote learning in 2020 made the need to move these exams online essential. The goal of the exams is to measure student learning so as to place students in the best subjects to ensure their long-term success at MIT, and the online exams did a fair job of measuring competency. We will explore the results of this first exam to refine and improve on these exams and test questions in correlation with class performance over the next year.

The long-term objective is to have all of the core subjects (18.01–18.06) in an MITx/edX format; 18.05 Introduction to Probability and Statistics and 18.06 Linear Algebra are next on the list. The time needed to do this continues to be the main challenge to faculty members who contribute to these efforts. The support of the Digital Learning Laboratory for the efforts of department scientists and fellows to develop digital content is essential to the successful running of these classes at MIT as well as on edX.

### **Graduate Students**

There were 125 graduate students in mathematics in AY2020, all in the PhD program. A total of 26 students received their doctoral degrees between September 2019 and June 2020, and one student left the program with a master's degree.

A majority of students who completed their PhD degrees advanced to postdoctoral positions in mathematics and related departments at other universities. These included appointments at the Institute for Advanced Study, the California Institute of Technology, Columbia University, Stanford University, the University of California at Berkeley, UCLA, the University of California at San Diego, the University of Chicago, the University of Georgia, the University of Michigan, and the University of Pennsylvania. Students also moved on to international appointments at the Universities of Bonn, Cambridge, and Oxford; the KTH Royal Institute of Technology; and University College London. A smaller number elected to pursue jobs in industry, with the most popular options including jobs in finance and research scientist positions at companies such as Facebook and MathWorks.

Twenty-two new students will enter the mathematics doctoral program in September 2020. The entering class includes four women. The department continues the policy of offering all first-year doctoral students full fellowship support and guaranteed support for five academic years.

### **Graduate Awards**

Graduate students Oscar Mickelin and Chengzhao (Richard) Zhang each received the Charles and Holly Housman Award for Excellence in Teaching for their exceptional skill in and dedication to undergraduate teaching. The Charles W. and Jennifer C. Johnson Prize for an outstanding research paper accepted in a major journal was awarded to graduate student Andrew Ahn.

### **Mathematics Majors**

The mathematics major is the third largest major at MIT and the largest within the School of Science. According to the official fall fifth-week tally for AY2020, 377 students listed mathematics as their major: 270 were in Course 18 (Mathematics) and 107 were in Course 18C (Mathematics with Computer Science). Enrollment had increased to 395 undergraduates by the spring 2020 term (somewhat lower than our usual 400 or more undergraduates due to the absence of early sophomore standing this spring). Of these students, 135 graduated with bachelor's degrees in mathematics (84 with mathematics as a first major and 51 with mathematics as a second major).

The number of responses to the department's senior survey was far below our usual yield in this pandemic spring; however, of the 54 students whose postgraduate plans are known, 13 will continue in graduate programs in mathematics, eight in programs in computer science, two in programs in physics, and one each in computational biology, economics, and optical sciences. A similar number will pursue non-academic opportunities, with six entering jobs in computing and software engineering, 14 entering the financial sector, two joining consulting companies, two working as data scientists/analysts, and several taking a year off to travel or continue job searching.

### ***Undergraduate Awards***

The Jon A. Bucsela Prize in Mathematics, given in recognition of distinguished scholastic achievement, professional promise, and enthusiasm for mathematics by a mathematics major, was awarded to seniors Anlong Chua and Douglas Stryker. Senior Marisa Gaetz received honorable mention for the Alice T. Schafer Prize for excellence in mathematics by an undergraduate woman.

### ***Putnam Triumphs***

MIT continued to dominate the William Lowell Putnam Mathematical Competition. The results this year were the most dominant by any university ever. All five Putnam Fellows, the top ranked individuals, were from MIT, followed by nine of the next 11 "Highest Ranking Individuals" and eight of the following 12. This was the first year that an institution's ranking was determined by its top three scorers (previously it was based on the scores of three preselected individuals). As such, MIT was the winning team. In addition, one of the three Elizabeth Lowell Putnam Prizes (awarded to the highest scoring women) went to junior Qi Qi from MIT. (In fact, MIT first-year female undergraduate Dain Kim actually scored higher than any of the Elizabeth Lowell Putnam winners but neglected to ask to be considered for the prize.) In total, MIT students accounted for 55 of the 108 test takers who received honorable mention or higher. Members of our winning team were senior Ashwin Sah, sophomore Shengtong Zhang, and first-year student Daniel Zhu; they were joined by senior Kevin Sun and junior Yuan Yao to complete the list of Putnam Fellows. Among the three top scorers (Sah, Zhang, and Zhu), two earned a nearly perfect score, and one (who preferred not to be named) earned a perfect score of 120 points. This is only the fifth time in Putnam's history that a test taker received a perfect score. Students benefited from excellent coaching by Professor Yufei Zhao.

### ***Undergraduate and High School Summer Research Programs***

#### ***Summer Program in Undergraduate Research***

In summer 2019, the department hosted its 23rd Summer Program in Undergraduate Research (SPUR), a six-week intensive mathematical research experience for MIT undergraduates in which each undergraduate pursues an individual or team project with a graduate student mentor. There is also a SPUR+ version that targets top women and members of minority groups and begins three weeks earlier. The summer 2019 SPUR+ proved successful in expanding the overall program to more women and underrepresented minority (URM) students. Altogether, 10 MIT undergraduates

participated in the 2019 SPUR program (including four female students) and four in the SPUR+ program (three underrepresented minority students and one female student), mentored by nine graduate students. The Hartley Rogers Jr. Prize for best project was shared by SPUR teams Yuan Yao '21, Shengtong Zhang '22, and mentor Jonathan Tidor; Douglas Stryker '20 and mentor Ao Sun; and Quiyu Ren '21 and mentor Yuqui Fu. Ankur Moitra and Professor David Jerison continued in their role as faculty supervisors.

### ***Research Science Institute***

Summer 2019 was the 27th year of the department's participation in the Research Science Institute program for gifted high school students. Nine graduate students mentored 10 high school students in the six-week program. The students came from eight different states as well as Bulgaria and Kazakhstan. Dimitar Chakarov and AnaMaría Perez were finalists at the 2020 Regeneron International Science and Engineering Fair (ISEF) for their research projects, and Jason Liu was a finalist in the 2020 Regeneron Science Talent Search.

### ***Program for Research in Mathematics, Engineering, and Science***

Calendar year 2020 was the 10th year of our Program for Research in Mathematics, Engineering, and Science. Twenty-two gifted high school students from the greater Boston area worked with eight postdoctoral researchers and graduate student mentors on research projects or participated in reading groups in the mathematical section of PRIMES. Additionally, in the PRIMES-USA math section, 40 exceptional out-of-state students selected from a national pool conducted research projects or participated in reading groups under the supervision of 26 graduate students, postdoctoral associates, and outside faculty.

In fall 2019, PRIMES and PRIMES-USA math students successfully completed 27 individual and group research projects they had worked on during calendar year 2019. Rupert Li won fourth place in the 2020 Regeneron Science Talent Search competition; three other students were finalists, and eight won national scholar awards. Rupert Li also was a finalist at the 2020 Regeneron ISEF. A number of math students received honors at the 2019 Yau High School Science Award competition: Ziyang Lei won the Global Gold Math Award, Christopher Zhu the Global Math Award, Victoria Zhang the Global Silver Physics Award, and Benjamin Kang the Global Bronze Economic and Financial Modeling Award. Six other students were US semifinalists in mathematics and in computer science. In addition, four students received Outstanding Presentation Awards at the Mathematical Association of America's Undergraduate Student Poster Session at the 2020 Joint Mathematics Meetings.

PRIMES Circle and MathROOTS are more specifically designed for female and underrepresented minority high school students than other PRIMES programs. PRIMES Circle completed its eighth year, offering an enrichment curriculum for students in the Boston area. A total of 19 students from urban public high schools, including four Hispanic students, one African American student, and 11 female students, participated in the 2020 program.

Due to the pandemic, all PRIMES activities since mid-March 2020 have been conducted online.

From June 19 through July 3, 2020, the department hosted its sixth MathROOTS summer camp program, with all camp activities conducted online. A total of 20 students participated; seven self-identified as female, seven as African American, 11 as Hispanic, and two as Native American–Latino. Thus far, of 100 MathROOTS alumni (from 2015–2019), 37 students have enrolled at or delayed entry to MIT.

In June 2020, PRIMES held its 10th annual spring-term conference online. Organized by Pavel Etingof and Slava Gerovitch, the conference featured 23 presentations by nearly 50 students from MIT PRIMES, PRIMES Circle, and the PRIMES Solve-Theorize-Explore-Prove (STEP) program for seventh- to ninth-grade students. This well-attended event demonstrated the solid success of the program. Several projects will likely lead to publication in professional journals and will be strong contenders at national science competitions for high school students. The remaining PRIMES and PRIMES-USA students will present their projects at the fall-term online conference in October 2020.

Twenty PRIMES alumni will enroll at or delay entry to MIT as first-year students in fall 2020 and will likely continue their research through the Undergraduate Research Opportunities Program.

### ***Lusztig Mentors***

Through the generosity of Professor George Lusztig, the Lusztig PRIMES mentorships are awarded annually to continuing PRIMES mathematics mentors for exceptional mentoring service in prior years. The 2020 Lusztig PRIMES mentors were graduate students Vishal Arul, Yongyi Chen, and Kaavya Valiveti.

## **Building Diversity**

### **MIT's #ShutDownSTEM Day-Long Event**

Between the campus lockdown in March 2020 and the intensification of Black Lives Matter (energized particularly by the death of George Floyd on May 25, 2020), the department participated in the Institute and School of Science's global academic community event #ShutDownSTEM on June 10, 2020. It was a day of reflection to learn and address the practices and impacts of systemic racism in academia.

The Mathematics Department organized a full day of presentations, breakout sessions, and community discussions, including a listing of pre-event readings relevant to mathematicians and academia.

Adjunct Professor Henry Cohn and Principal Research Scientist Andrew Sutherland hosted the daylong program, providing much of its organization and technical support. Professor Goemans opened the plenary session with readings by faculty and staff. This was followed by the observed 8 minutes and 46 minutes of silence in memory of George Floyd, with an accompanying scroll of other recent victims of anti-Black violence. Department members then split into five breakout sessions with leaders and monitors having prepared materials to guide each session. Afterward, participants rejoined the plenary session to hear summaries of each session and engage in discussion.



The day was an inspiration for the department to explore new formats for learning and interaction and help identify hidden practices of institutional racism, sexism, and other prejudices in academic mathematics. In AY2021, we will be looking to expand the department's diversity web page as a resource for community building, facilitate peer mentorship, and highlight first-person narratives from department members who are from underrepresented communities.

One new activity was a reading group seminar on diversity issues, open to community members. Professor Tomasz Mrowka and Peter Haine, a graduate student, organized a summer weekly reading seminar to examine the book *An Inclusive Academy: Achieving Diversity and Excellence* by Abigail Steward and Virginia Valian. The format included designating a participant to lead a discussion and prepare materials to move the discussion along. The summer session went from late June 24 through early August and will continue in AY2021.

### **Community Building among Mathematics Majors**

Gigliola Staffilani continued as head the Diversity and Community Building Committee. The committee met in October and February to discuss ongoing challenges with respect to increasing the department's diversity at all levels, beginning with MIT's undergraduates. Tomasz Mrowka followed Staffilani as the department's representative on the Diversity Council of the School of Science.

### **Reinforcing Community Values of Inclusion and Support**

A main topic at the October and February committee meetings was the observation, gleaned from various surveys, that a significant portion of mathematics majors feel underclass by their colleagues. MIT attracts perhaps the largest concentration of the most talented math students of any North American institution (as our Putnam Exam results would indicate). However, the math major is designed to accommodate not only these students but many other strong students less familiar with advanced subjects (not to mention those who double major in math). As part of our educational mission, we saw the need to instruct all math majors on the importance of inclusion of female and underrepresented minority students, as well as their colleagues at all levels. To this end, we designed a [code of conduct poster](#), modeled on one developed by the Physics Department with similar messaging, to mount in heavily traveled areas at key intersections on the first-floor hallway of the Simons Building classrooms. When the campus reopens, it should serve to remind students of our values as a mathematics community.

### **Ongoing Community Initiatives**

In AY2020 we saw a small incremental increase in diversity among the mathematics majors, to 36.4% women and 18% members of underrepresented minority groups. We are hopeful that this trend will continue.

This was the third year of the department's Math Puzzles Social, open to all undergraduates, hosted in October 2019, and the third year we opened the math daily teas to all undergraduates twice a week. In addition, it was the second year we invited incoming undergraduates at the Academic Expo to sign up on a database to keep abreast

of open department socials and events such as the alumni forums (including one titled From Here to Where) and panel presentations throughout the year.

The department completed the first year of its Open Advising Hours initiative for math majors and other undergraduates to obtain academic advice from math faculty (in addition to what they would have received from their assigned academic advisor). Faculty members volunteered on a rotating basis. Open Advising Hours was particularly designed to assist first-year students who are advanced in math but have not yet declared mathematics as a major (and hence do not have a math advisor). With the removal of the sophomore standing, the Office of the Vice Chancellor is less equipped to provide technical advice to first-year students. The program has been offered online since March and will continue in that format through at least the next fall term.

One community activity that had to be canceled this year due to the campus lockdown was the department's Pi Day celebration (March 14), initiated in AY2019 with pizza and activities for all members of the community including math majors.

### **Martin Luther King Visiting Professorship Program**

Professor Kasso Okoudjou, a member of the mathematics faculty at the University of Maryland, completed his second year as a Martin Luther King, Jr., Visiting Professor. He taught full time, continued his research program in applied harmonic analysis, and participated on the Diversity and Community Building Committee.

During the year, the department nominated two African American faculty for the AY2021 MLK visiting faculty program: Professor Sean Paul of the University of Wisconsin, Madison for a term and Assistant Professor Stephen J. Kleene of the University of Rochester for a full year. Both professors have had prior appointments in the Mathematics Department. While the department was not able to obtain MLK support from the equity office, the School of Science generously agreed to support both visiting professors' appointments. Professor Kleene has requested to come in AY2022, and Professor Paul has yet to decide his final schedule. Both will be teaching, advancing their research programs, and participating on the Diversity and Community Building Committee.

### **Directed Reading Program**

The Directed Reading Program pairs an undergraduate with a graduate student mentor to work through one or more math texts over the Independent Activities Period. The design has proven quite successful in years past in attracting undergraduates, particularly women and students from underrepresented minority groups. The department committed more funding to the program in AY2019, and consequently the program has seen a rise in undergraduate participants (from 24 in AY2018 to 51 in AY2020), with 25% women and 18% URM students in AY2020.

### **Building a Community for Women**

As with all late spring activities, the lockdown had to be accommodated. However, where online virtual participation was possible, these programs maintained their spring schedule. Below is the latest on our regular initiatives, with the addition of the

celebration of Women in Math Day. (Most of these events are scheduled to continue online in AY2021 for as long as necessary.)

- Last fall Professor Staffilani continued to host the annual Women in Mathematics dinner at her home in Cambridge for women faculty, postdocs, graduate students, and mathematicians in the greater Boston area, attracting more than 40 guests.
- The department's Women in Math Lunch Seminar series, scheduled to take place three to four times a term, hosts a senior woman mathematician to discuss her research and career in academia or industry. The seminar is open to women faculty, postdocs, graduate students, and undergraduates (whose participation has been increasing). The series continued via Zoom through the spring term.
- MIT women math majors and graduate students continue to offer girls in middle school mentoring at Girls' Angle: A Math Club for Girls in Cambridge. The department provided its head mentor, Professor Grace Work (Vanderbilt University), an affiliate appointment to have access to MIT's resources in AY2020. Since March, Girls' Angle has been able to maintain mentoring online but had to cancel its SUM+IT event (scheduled to be held at MIT), which arranges for girls to self-organize and collaborate on fun math projects.
- For the ninth consecutive year, the department hosted the Advantage Testing Foundation Math Prize for Girls competition for high school students, which took place over the Columbus Day weekend in 2019. In total, 268 young women from the United States and Canada competed for ranking and monetary awards, with the top 45 students invited to a mathematics prize Olympiad in November. The competition exposes strong young women math students to mathematics at MIT. More than half of the awardees have later matriculated at MIT.
- A new activity this year was the celebration of Women in Math Day (May 12), established by the International Mathematical Union's Committee for Women in Mathematics to celebrate women in mathematics worldwide. The department had planned a screening of the film *Secrets of the Surface: The Mathematical Vision of Maryam Mirzakhani* for the entire MIT community on May 8; however, due to the MIT closure in March the screening took place via Zoom only for women members of the department. The choice of May 8 was to accommodate MIT's academic calendar. Women in Math Day will continue to be celebrated with a community activity in future years.

### Other Initiatives

Professor Staffilani is also actively collaborating with the organizers of the Weekend Immersion in Science and Engineering (WISE) program. The MIT Office of Admissions organizes a pair of three-day-long events in which 100 top high school seniors from traditionally underrepresented communities are invited to visit MIT. Over the past two years, Professor Staffilani participated in the main student-faculty lunches and organized two math faculty tours for interested students. This year the tour will take place via Zoom.

The department maintains funding support for the following on-campus events and organizations for women, members of minority groups, and others:

- African Student Association Cultural Night
- Camp Kesem at MIT (a weeklong, free summer camp for children of cancer patients)
- MIT Spokes
- Ebony Affair (sponsored by the MIT Black Students' Union and Black Graduate Student Association)
- Society of Hispanic Professional Engineers at MIT
- Undergraduate Society for Women in Mathematics (which welcomes new women mathematics majors and arranges campus talks by outside women mathematicians)

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**Department Head**  
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