2018 Leroy P. Steele Prizes

Sergey Fomin   **Andrei Zelevinsky**   **Martin Aigner**   **Günter Ziegler**   **Jean Bourgain**

The 2018 Leroy P. Steele Prizes were presented at the 124th Annual Meeting of the AMS in San Diego, California, in January 2018. The Steele Prizes were awarded to SERGEY FOMIN and ANDREI ZELEVINSKY for Seminal Contribution to Research, to MARTIN AIGNER and GÜNTER ZIEGLER for Mathematical Exposition, and to JEAN BOURGAIN for Lifetime Achievement.

Citation for Seminal Contribution to Research: Sergey Fomin and Andrei Zelevinsky

The 2018 Steele Prize for Seminal Contribution to Research in Discrete Mathematics/Logic is awarded to Sergey Fomin and Andrei Zelevinsky (posthumously) for their paper "Cluster Algebras I: Foundations," published in 2002 in the *Journal of the American Mathematical Society.*

The paper "Cluster Algebras I: Foundations" is a modern exemplar of how combinatorial imagination can influence mathematics at large. Cluster algebras are commutative rings, generated by a collection of elements called cluster variables, grouped together into overlapping clusters. These variables are produced by a recursive combinatorial procedure called mutation, starting from an initial cluster of algebraically independent variables. Originally, cluster algebras were introduced to provide a combinatorial approach to total positivity in algebraic groups and Lusztig's canonical bases of quantum groups. However, in the fifteen years since their introduction, cluster algebras have been shown to be important in many seemingly different areas of mathematics, including root systems, Poisson geometry, Teichmüller theory, quiver representations, integrable systems, and quantum affine algebras. This paper is a work of lasting importance, both for its varied applications and for the intrinsic beauty of the theory.

Biographical Sketch: Sergey Fomin

Sergey Fomin is the Robert M. Thrall Collegiate Professor of Mathematics at the University of Michigan. Born in 1958 in Leningrad (now St. Petersburg), he received an MS (1979) and a PhD (1982) from Leningrad State University, where his advisor was Anatoly Vershik. He then held positions at St. Petersburg Electrotechnical University and the Institute for Informatics and Automation of the Russian Academy of Sciences. Starting in 1992, he worked in the United States, first at Massachusetts Institute of Technology and then, since 1999, at the University of Michigan.

Fomin's main research interests lie in algebraic combinatorics, including its interactions with various areas of mathematics such as representation theory, Schubert calculus, probability theory, and computational complexity. He is the current managing editor of the *Journal of the American Mathematical Society*, a member of the AMS Council, and a Fellow of the AMS. He served on advisory boards for MSRI and HSE Moscow and was an invited speaker at the International Congress of Mathematicians in Hyderabad in 2010.

Biographical Sketch: Andrei Zelevinsky

Andrei Zelevinsky was born in Moscow in 1953. A graduate of Moscow's famed High School #2, he studied at the mathematics department of the Moscow State University (PhD, 1978), where his main mentors were Joseph Bernstein, Israel Gelfand, and Alexandre Kirillov. He worked at

the Institute of Earth Physics and at the Scientific Council for Cybernetics of the Soviet Academy of Sciences before moving to the United States in 1990. After a year at Cornell University, he took up a professorship at Northeastern University in Boston, where he remained until his untimely death in April 2013.

Andrei Zelevinsky made fundamental contributions to representation theory of p-adic groups (with Bernstein), generalized hypergeometric systems (with Gelfand and M. Kapranov), and algebraic combinatorics, total positivity, quiver representations, and cluster algebras (with various collaborators). He was an invited speaker at the ICM in Berlin (1998), a Fellow of the AMS (2012), and a recipient of the Humboldt Research Award (2004). He served on the Scientific Advisory Committee of MSRI and on editorial boards of several leading research journals. Northeastern University posthumously honored Zelevinsky by a Distinguished University Professorship and by inaugurating a postdoctoral program named after him, the Andrei Zelevinsky Research Instructorships.

Response from Sergey Fomin

It is a great honor to receive the Leroy P. Steele Prize from the AMS. I am thankful to the prize committee for their selection. I would like to view it as a sign of appreciation for the inherent beauty and importance of the field of algebraic combinatorics, the mathematical love of my life.

The feeling is bittersweet, as my coauthor Andrei Zelevinsky did not live to enjoy this recognition of his research accomplishments. He was a dear friend, an inspiring teacher, and a brilliant mathematician.

Although Andrei and I lived until our mid-thirties in Moscow and St. Petersburg, a short train ride from each other, we first met in 1992 in Boston, where our 20-year-long collaboration took root. I am forever thankful to the fate—and to Andrei—for this most momentous partnership of my professional life.

We discovered cluster algebras in May 2000 at the Erwin Schrödinger Institute in Vienna. George Lusztig's pioneering work on total positivity and canonical bases was a major source of inspiration. Our mathematical tastes and philosophies were deeply influenced by our mentors Joseph Bernstein, I. M. Gelfand, Richard Stanley, and A. M. Vershik. Last but not least, I would like to acknowledge the great many mathematicians who over the years contributed to the development of the theory of cluster algebras. I hope that this field continues to thrive, finding new exciting applications.

Citation for Mathematical Exposition: Martin Aigner and Günter Ziegler

The 2018 Steele Prize for Mathematical Exposition is awarded to Martin Aigner and Günter M. Ziegler of the Freie Universität Berlin for *Proofs from THE BOOK*. It is almost impossible to write a mathematics book that can be read and enjoyed by people of all levels and backgrounds, yet Aigner and Ziegler accomplish this feat of exposition with virtuoso style. The inspiration for this book is Paul Erdős's assertion that there is a celestial book where perfect proofs are kept. In *Proofs from THE BOOK*, the authors have collected a great number of sparkling little mathematical gems that are their candidates for Erdős's book. These mathematical vignettes are drawn from number theory, geometry, analysis, combinatorics, and graph theory. Most of the topics in the book require only a modest mathematical background, so that it is suitable for undergraduates and mathematically inclined nonspecialists. This is not to say that the mathematics is simple—even if the masterful exposition often makes it seem that way; there are answers to questions asked by Hilbert, Borsuk, Sylvester, and, of course, Erdős himself. For the research mathematician, the appeal of the book is that the proofs themselves are indeed beautiful. Aigner and Ziegler have succeeded in writing a book in which the density of elegant ideas per page is extraordinarily high, and they sustain this quality throughout the text. It is also worth noting that it is not just the mathematics that is aesthetically pleasing; the authors did the typesetting themselves, and the cartoons by mathematician Karl Heinrich Hofmann add a light-hearted touch. This book does an invaluable service to mathematics, by illustrating for nonmathematicians what it is that mathematicians mean when they speak about beauty.

Biographical Sketch: Martin Aigner

Martin Aigner was born in 1942 in Linz, Austria. In 1960 he started his studies of mathematics, physics, and philosophy at the University of Vienna and received his PhD in mathematics from the same university in 1965. After shorter stays at various institutions in the United States, he worked from 1968 to 1970 as research associate with Raj Chandra Bose at the University of North Carolina at Chapel Hill during the Special Combinatorics Year Program. He moved to Tübingen, Germany, with a Habilitations-Fellowship of the German Science Foundation in 1970 and became professor at the Freie Universität Berlin in 1973. He has been in Berlin ever since, from 2010 on as professor emeritus.

His field of research is enumerative and algebraic combinatorics, graph theory, and search theory. He is the author of twelve books, among them the monographs *Combinatorial Theory* (Springer, 1979), reprinted in the Springer Classics in Mathematics series (1997); *Combinatorial Search* (1988); *A Course in Combinatorics* (2007); and *Proofs from THE BOOK* (with Günter M. Ziegler, Springer 1998++), which is available in fourteen languages.

He is a member of the Austrian Academy of Sciences and the Berlin-Brandenburg Academy of Sciences and Humanities. In 1996 he received the Lester R. Ford Award of the MAA. He was the Richard-Rado-Lecturer at the British Combinatorial Conference in 2001 and acted as vice president of the Organizing Committee for the International Congress of Mathematicians 1998 in Berlin.

Biographical Sketch: Günter Ziegler

Günter M. Ziegler was born in München, Germany, in 1963. He got a PhD at the Massachusetts Institute of Technology with Anders Björner in 1987. After four years in Augsburg

and a winter in Stockholm, he arrived in Berlin in 1992. In 1995 he became a professor of mathematics at TU Berlin; in 2011 he moved to Freie Universität Berlin. He has been a member of the DFG Research Center MATHEON (Mathematics for Key Technologies) since its start in 2002. He was the founding chair of the Berlin Mathematical School, which he now chairs again.

In 2006–2008 he was the president of the German Mathematical Society (DMV). He is a member of the executive board of the Berlin-Brandenburg Academy of Sciences and Humanities, a member of the German National Academy of Sciences Leopoldina, and an inaugural Fellow of the AMS. Since 2014 he is a member of the Senate of the German Science Foundation (DFG). His research centers on discrete geometry (especially polytopes), as well as on questions in algebraic topology motivated by geometric problems. His honors include a gold medal at the International Mathematics Olympiad (1981), a DFG Leibniz Prize (2001), an ERC Advanced Grant (2010), and the 2004 Chauvenet Prize of the MAA.

He is active in science communication, contributing to a multifaceted and lively image of mathematics in public. He initiated and coorganized the German National Mathematics Year 2008 and now directs the DMV Mathematics Media Office. He is the recipient of the 2008 Communicator Award of DFG and Stifterverband.

His books include *Lectures on Polytopes* (Springer, 1995), *Proofs from THE BOOK* (with Martin Aigner, Springer, 1998++), and *Do I Count? Stories from Mathematics* (CRC, 2013).

Response from Martin Aigner and Günter M. Ziegler

We feel very honored to receive the Leroy P. Steele Prize for Mathematical Exposition for our book *Proofs from THE BOOK*.

It was more than twenty years ago that the idea for this project was born during some leisurely discussions with the incomparable Paul Erdős at the Mathematisches Forschungsinstitut in Oberwolfach. We suggested to him that we turn his famous saying of the celestial book (in which God keeps the perfect proofs for mathematical theorems) into a first (and very modest) approximation to *THE BOOK*. He was enthusiastic about the idea and suggested right away a few examples. Our book was supposed to appear in March 1998 as a present to Erdős for his eighty-fifth birthday. With Paul's unfortunate death in 1996, the book is instead dedicated to his memory.

We have no definition or characterization of what constitutes a proof from *THE BOOK*: All we offer is the examples that we have selected, hoping that the readers would share our enthusiasm about brilliant ideas, clever insights, and wonderful observations. To make the book attractive to a large readership, we selected only topics that require a modest mathematical background but would still be interesting for the research mathematician for the sheer beauty of the argument or the intriguing open problems that remained. A lot of energy and care went into the most elegant and appealing presentation of the results

and proofs that we could achieve. A book about beauty in mathematics naturally requires an equally attractive appearance. An enormous amount of time went into the crafting of the text and the margins, the selection of the photos, and the pictures and illustrations. We are very grateful to Karl H. Hofmann for his masterful cartoons that put the final touch to the makeup of the book.

At the time when we started the project, we could not possibly imagine the wonderful and lasting response our book about THE BOOK would have, with all the warm letters and interesting comments, new editions, and thirteen translations as of now. It has grown over the years from thirty to forty-five chapters, and as suggestions for new chapters are coming in every month, who knows.... We are extremely thankful for this warm reception and seemingly never-ending interest. It is no exaggeration to say that *THE BOOK* has become a part of our lives.

Citation for Lifetime Achievement: Jean Bourgain

The 2018 Steele Prize for Lifetime Achievement is awarded to Jean Bourgain, IBM von Neumann Professor in the School of Mathematics at the Institute for Advanced Study, for the breadth of his contributions made in the advancement of mathematics.

Jean Bourgain is a giant in the field of mathematical analysis, which he has applied broadly and to great effect. In many instances, he provided foundations for entirely new areas of study, and in other instances he gave mathematics new tools and techniques. He has solved long-standing problems in Banach space theory, harmonic analysis, partial differential equations, and Hamiltonian dynamics. His work has had important consequences in probability theory, ergodic theory, combinatorics, number theory, computer science, and theoretical physics. His vision, technical power and broad accomplishments are astounding.

Bourgain has so many striking results to his credit that it is difficult to select his most important contributions. His breakthroughs include the highly original proof of global existence for critical nonlinear Schrödinger equations—a proof whose techniques have been universally adopted; the first proof of the invariance of the Gibbs measure associated to certain infinite-dimensional Hamiltonian systems—a work that bridges partial differential equations, probability theory and mathematical physics; and the proof of the local Erdős-Volkmann Ring Conjecture—a proof that laid the groundwork for the so-called Sum-Product Theory and its subsequent development. With Alex Kontorovich, Bourgain developed the "circle method," which has striking applications to integral Apollonian packings and the Zaremba Conjecture. In recent breakthroughs, Bourgain and Ciprian Demeter proved the l^2 Decoupling Conjecture, and Bourgain, Demeter, and Larry Guth proved the Vinogradov Mean Value Theorem.

Biographical Sketch: Jean Bourgain

Jean Bourgain was born in 1954 in Oostende, Belgium. He earned his PhD in 1977 under the supervision of Freddy Delbaen. From 1975 until 1984 he held a position at the

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Belgian Science Foundation. In 1985 he was appointed to the IHES faculty, and the same year he also started a half-time position at the University of Illinois as J. L. Doob Professor. He joined the Institute for Advanced Study in 1994 as part of the School of Mathematics.

Bourgain was elected Associé Entranger de l'Academie des Sciences in 2000, Foreign Member of the Polish Academy in 2000, Foreign Member of Academia Europea in 2008, Foreign Member of the Royal Swedish Academy of Sciences in 2009, Foreign Associate of the National Academy of Sciences in 2011, and Foreign Member of the Royal Flemish Academy of Arts and Sciences in 2013.

Bourgain has been awarded numerous prizes and awards, including the Alumni Prize, Belgium NSF (1979); the Empain Prize, Belgium NSF (1983); the Salem Prize (1983); the Damary-Deleeuw-Bourlart Prize (1985); the Langevin Prize (1985); the E. Cartan Prize (1990); the Ostrowski Prize (1991); the Fields Medal (1994); the I. V. Vernadski Gold Medal (2010); the Shaw Prize (2010); the Crafoord Prize (2012); the title of Baron of Belgium (2016); and the Breakthrough Prize in Mathematics (2017).

Response from Jean Bourgain

I am deeply honored and grateful to receive the 2018 Steele Prize for Lifetime Achievement. Over the years, I have been fortunate to meet and interact with some remarkable individuals, with different interests and styles, from whom I learned a lot. They played a decisive role in introducing me to new subjects and encouraging my research. A large part of my work is also the result of fruitful collaborations with both junior and senior researchers, sometimes over an extended period of time. I am most grateful to them.

Exceptional working conditions also allowed me full scientific dedication. At an early career stage, it was an appointment at the Belgian Science Foundation. Later, in the mid-1980s, a professorship at the IHES in Bures/Yvette and at the University of Illinois Urbana—Champaign, and since 1994 at the Institute for Advanced Study in Princeton. The intensity of scientific life and exposure to new ideas they offer was and is a great experience, and I would like to thank them for their trust.

At the present time mathematics is an extremely active science and its future bodes well for its constant progress, both for solving old problems and opening new areas of research.

About the Prizes

The Steele Prizes were established in 1970 in honor of George David Birkhoff, William Fogg Osgood, and William Caspar Graustein. Osgood was president of the AMS during 1905–1906, and Birkhoff served in that capacity during 1925–1926. The prizes are endowed under the terms of a bequest from Leroy P. Steele. Up to three prizes are awarded each year in the following categories: (1) Lifetime Achievement: for the cumulative influence of the total mathematical work of the recipient, high level of research over a period of time, particular influence on the development of a field, and influence on mathematics through PhD students; (2) Mathematical Exposition: for a

book or substantial survey or expository research paper; (3) Seminal Contribution to Research: for a paper, whether recent or not, that has proved to be of fundamental or lasting importance in its field or a model of important research. The Prize for Seminal Contribution to Research is awarded on a six-year cycle of subject areas. The 2018 prize was given in discrete mathematics/logic; the 2019 prize is open; the 2020 prize is in analysis/probability; the 2021 prize is in algebra/number theory; and the 2022 prize is in applied mathematics.

The Steele Prizes for Mathematical Exposition and Seminal Contribution to Research carry a cash award of US$5,000; the Prize for Lifetime Achievement, a cash award of US$10,000.

The Steele Prizes are awarded by the AMS Council acting on the recommendation of a selection committee. The members of the committee for the 2018 Steele Prizes were:

- Tobias H. Colding
- Simon Donaldson
- Phillip Griffiths
- Carlos E. Kenig (Chair)
- Nancy J. Kopell
- Vladimir Markovic
- Yuval Peres
- Victor Reiner
- Thomas Warren Scanlon

A list of previous recipients of the Steele Prize may be found on the AMS website at www.ams.org/profession/prizes-awards/ams-prizes/steele-prize.

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