Report of

Science at Williams

2020-2021


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Report of Science at Williams College 2020-2021

A record of the professional and academic activites of faculty and students in the natural sciences

Williamstown, Massachusetts

Cover Photos

Front: A view from the Science Quad of the Wachenheim Science Center which was completed for the Spring semester of 2021. This modern new facilty is home to the Geosciences, Mathematics/Statistics, and Psychology departments and also provides a large amount of new teaching space. This building adds another outstanding and attractive learning environment for Williams College science students to prosper in for generations to come.

Back: *theBIOquilt,* created by our own Debra Rogers-Gillig (Technical Assistant in Biology) in collaboration with Theresa Raymond Levine was finished and hung prominently in the main central stairway of The Hopper. The quilt measures 10 feet by 10 feet and depicts various disciplines within the Biology Department.

View of the Wachenheim Scsience Center from the North end. A wide paved pathway leads to the Science Quad past a wall of windows belonging to the new Frank Morgan Math Library.

The Science Executive Committee wishes to express its gratitude to the many contributors to this document and especially to the extensive efforts of all of the administrative assistants in the various science departments.

Editor: Norman Bell, Science Center Manager

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Williams College admits men and women of any background to all the rights, privileges, programs and activities generally accorded or made available to students at the College. It does not discriminate on the basis of race, color, religion, creed, sexual orientation, or national ethnic origin in administration of its educational policies, scholarship and loan programs, and athletic and other college administered programs. The College does not discriminate on the basis of sex in violation of the Title IX of the Education Amendments of 1973, or the regulations thereunder, in the education programs or activities which it operates, including employment therein. The College does not discriminate on the basis of handicap in violation of Section 504 of the Rehabilitation Act 1973, or the regulations thereunder, in admission or access to its programs and activities. Inquiries concerning the College's non-discrimination policies may be referred to the Dean of the College, Hopkins Hall, Williamstown, MA 01267.

CONTENTS

Four generations of science buildings: In this photo can be seen (from left): Wachenheim Science Center (2021), Thompson Biology Labs (1896), Morley Science Center (1999), and The Hopper Science Center (2018). These buildings along with the Thompson Chemistry and Physics Lab buildings combine to form one intergrated and contiguous building to house the eight Division III departments of Williams College.

The Sciences at Williams

Students learn science best by doing science; that is by formulating and testing their own hypotheses using methods capable of producing convincing evidence. This is true at the introductory level, where students become interested in further study by encountering science as discovery rather than rote facts. It is even more important at advanced levels, where students are most likely to become interested in science careers by working as fully involved junior colleagues with professionally active faculty on research projects that explore new scientific ideas. The ability to conduct cutting-edge research at Williams helps to attract talented scientists as faculty and keeps them at the forefront of their disciplines, which in turn allows faculty to bring the excitement of their research work to their teaching and course development at all levels. The College has invested deeply in this ambitious program of research and teaching through research funding, modern laboratory space, shared instrumentation, and technical support. The relatively large number of faculty in all the science departments promotes breadth and depth in both research activities and curricular scope.

In May of 2018 phase I of a major expansion of the science center complex was completed with the addition of *The Hopper Science Center,* a new facility to house 27 faculty offices and research labs in Biology, Chemistry and Physics. The new building also greatly expanded our microscopy and shop facilities to support all of the sciences and includes an updated teaching lab for biochemistry courses. Upon completion of The Hopper, we immediately commenced design and construction of a second building to House the Geosciences, Mathematics/Statistics and Psychology departments. We are happy to report that in the Spring of 2021, these three departments moved into their new home in the *Wachenheim Science Center* and the building is now a fully fuctioning facility. Photos of the new building are sprinked throughout this report.

Our model of the sciences as a cohesive programmatic unit continues to flourish. Funding for major equipment, for individual student-faculty research, and summer stipend support for student research at Williams are coordinated on a division-wide basis by the Science Center Director, the Science Executive Committee and the Divisional Research Funding Committee. Working together, we are able to share not only facilities and equipment, but also ideas and enthusiasm, and so provide a "critical mass" of activity that might not be possible within an individual department at a small institution.

This year we welcomed the Psychology department into the Division III curriculum which formalized their place in the sciences which they have long called their home. Each year, more than 250 students complete a major in a science discipline, and we continue to see about half of all students at Williams College with at least one major in the sciences. The quality of the our science programs has nurtured this interest and this year 71 students were inducted into the Sigma Xi Honor Society as associate members. Williams has become a leader in the training of future scientists with typically more than 50 graduates entering Ph.D. programs in science each year. As a result of this commitment, Williams has ranked first among predominantly undergraduate institutions in students receiving NSF pre-doctoral fellowships, averaging about 7 per year over the past ten years. We attribute this success to an energetic faculty and staff dedicated to providing an excellent educational experience and to the many research opportunities available to Williams students at both advanced and introductory levels.

A positive undergraduate research experience is the single most important inspiration for future scientists. This year, 98 students completed theses and 221 were engaged in research with science faculty during the summer of 2020 with many more working in labs during the school year. 52 current and recent students contributed to peer-reviewed journals in the past academic year.

Concurrent with the increased student involvement in science, Williams has attracted talented and vibrant science faculty engaged in competitive research and dedicated to teaching undergraduates. As a result, the number of external grants awarded to support faculty research or curricular innovation places Williams near the top of all non-Ph.D granting institutions. Williams science faculty currently have over 30 active research grants totalling over 2.4 million dollars. The individual faculty grants, together with grants from the Sherman Fairchild Foundation, the Henry Luce Foundation, endowed funds from the Kresge, and Keck Foundations, and other sources, has enabled us to purchase and maintain state-of-the-art equipment for teaching and research. Advanced equipment and facilities together with our Emphasis on close student-faculty interactions creates opportunities in undergraduate science education at Williams that are exciting, diverse, and forward-looking.

MAJOR SCIENCE FUNDING

Kresge Foundation Equipment Grant

Williams was awarded a large grant from the Kresge Foundation in 1990 to replace and update major items of scientific equipment and instrumentation. This grant is used to purchase new equipment, to support maintenance contracts and to repair existing instruments, and also to support technical staff members who oversee the instruments. One aspect of the grant is that the College sets aside endowment funds for the depreciation and eventual replacement of items purchased under the grant. Through this grant the college has purchased and maintains a 24-inch optical telescope, a gas chromatograph mass spectrometer, a MALDI-TOF mas spectrometer, transmission and scanning electron microscopes, a UV/Vis/NIR spectrophotometer, an x-ray diffraction instrument a confocal microscope and a nuclear magnetic resonance spectrometer (NMR). In recent years, Kresge endowment funds have been used to upgrade the telescope and NMR and replace the confocal and transmission electron microscopes.

These expensive pieces of core equipment are heavily used by faculty and students in collaborative research projects and in teaching laboratories associated with courses ranging from introductory to advanced levels. We are dedicated to continue to use these resources to provide state of the art equipment for research and teaching efforts in the sciences at Williams College.

Clare Boothe Luce Research Scholarships

Funded by the Henry Luce Foundation, the Clare Boothe Luce research scholars grant seeks to increase the number of female students at Williams who declare majors in the physical sciences (Astrophysics, Computer Science, Geosciences, Mathematics/Statistics, and Physics) and increases the proportion of women in these fields conducting honors thesis research and pursuing doctoral degrees and careers in science. The Clare Boothe Luce research grant initially supported cohorts of up to eight women each year for three years with funding for summer research stipends, research supplies and equipment, and attendance at professional conferences. Williams College supports the Clare Boothe Luce scholars program with funds for a second year of honors theses related research and funds programmatic enhancements such as visits from CBL professors, cohort-building events during the academic year, and discussion sessions with Williams alumnae currently in graduate school. After the initial 3 year funding period expired, the grant has been continued and has funded outstanding women in the physical sciences in subsequent years. In the 2020-21 year, the grant supported five student researchers.

SMALL

Each summer the Math/Stats department runs a 10-week Research Experience for Undergraduates (REU) Program to introduce students to research. Named SMALL after the leading letters of the last names of the five founders, it is now in its 31st year. Funded primarily by the NSF and Williams, about 30 students each summer work in small groups closely with their advisor on open research problems, which are frequently in current, active areas of mathematics and statistics. Over 500 students have participated, now writing more than 10 papers each year and giving talks on their work the world over, from the Joint Mathematics Meetings to meetings in Canada, Japan, and Spain. Recent topics include combinatorics, commutative algebra, ergodic theory, geometric origami, geometry, knot theory, multidimensional continued fractions, mathematical physics, number theory, probability and statistics. See http://math.williams.edu/small/ for more information.

For additional external funding sources supporting science center activities, see the chart on page 16.

MAJOR PROGRAMS

The **Astronomy** Department offers courses for students interested in studying and learning about the universe, and who would like to be able to follow new astronomical discoveries as they are made. Students can choose between broad non-mathematical survey courses (ASTR 101, 102 or 104) and a more intensive introductory course (ASTR 111) designed for those planning further study in astronomy or another science. All students in the introductory courses use the 24-inch telescope and other telescopes and instruments on the observing deck to study astronomical objects. The astrophysics major, administered jointly with the Physics Department, is designed primarily for students who plan graduate study in astronomy, astrophysics or a related field. The major emphasizes the structure of the universe and its constituents in terms of physical processes. This including the Sun, stars and star clusters, galaxies and galaxy clusters, quasars and active galaxies, and the cosmic background radiation. Majors in astrophysics usually begin their program with Introduction to Astrophysics (ASTR 111) as well as introductory physics courses. Intermediate and advanced level seminars introduce majors to current research topics in astronomy, while parallel study of physics completes their preparation for graduate work in astronomy or employment in a related field. The astronomy major is designed for students with a serious intellectual interest in learning about modern astronomy, but who do not wish to undertake all of the physics and math required for the more intensive astrophysics major. The astronomy major emphasizes understanding the observed properties of the physical systems that comprise the known universe. Students considering a major in the Astronomy Department, or a double major including Astronomy or Astrophysics, should consult with members of the Department about appropriate beginning courses. Independent research, extensive use of observational and image processing computer facilities, fieldwork at remote observatories or on eclipse expeditions and close working relationships with faculty are hallmarks of the Astronomy and Astrophysics majors.

The Williams College **Biology** Department curriculum has been designed not only to keep pace with new developments in the field, but also to afford students as broad a base as possible for understanding the principles governing life processes. Four courses, The Cell (BIOL 101), The Organism (BIOL 102), Genetics (BIOL 202) and a 400-level senior seminar, are required for the major. In addition, five electives may be selected from a wide range of courses including those in animal behavior, biochemistry, cellular biology, developmental biology, ecology and evolution, immunology, molecular biology, neurobiology, and physiology. New courses are continually added to our curriculum as new faculty are hired with diverse research expertise. Every course changes from year to year to emphasize the latest concepts and to introduce and integrate new techniques and instrumentation used in modern biological research. Although the biology major is specifically designed to provide a balanced curriculum in the broader context of the liberal arts for any interested student, it is also an excellent preparation for graduate studies in medicine and life sciences.

The **Biochemistry and Molecular Biology (BIMO)** Program is designed to provide students with an opportunity to explore living systems on the molecular level. Biochemistry and molecular biology are dynamic fields that lie at the interface between biology and chemistry. Current applications range from the diagnosis and treatment of disease to enzyme chemistry, developmental biology, and the engineering of new crop plants. After completing the introductory biology and chemistry courses and organic chemistry, a student would normally take the introductory course in the program: Biochemistry I – Structure and Function of Biological Molecules (BIMO 321) and Biochemistry II Metabolism (BIMO 322). These courses, taken in conjunction with courses in genetics and molecular genetics, establish a solid background in biochemistry and molecular biology. The advanced courses and electives available from the chemistry and biology department offerings encourage students' exploration of individual interests in a wide variety of topics. A senior capstone course, Topics in Biochemistry and Molecular Biology (BIMO 401), gives students the chance to explore the scientific literature in a variety of BIMO related research areas. Completion of the BIMO Program provides exceptional preparation for graduate study in all aspects of biochemistry, molecular biology, and the medical sciences.

Through a variety of individual courses and sequential programs, the **Chemistry** Department provides an opportunity for students to explore chemistry, an area of important knowledge about ourselves and the world around us. Those who elect to major in chemistry begin their studies with one of the Department's three gateway courses: CHEM 151 (Introductory Chemistry), CHEM 153 (the most commonly enrolled gateway course), or CHEM 155, depending on previous chemistry background and results of the Chemistry Placement Survey. The gateway course is followed by intermediate and advanced courses in organic, inorganic, physical, and biological chemistry. These provide a thorough preparation for graduate study in chemistry, chemical engineering, biochemistry, environmental science, materials science, medicine and the medical sciences. Advanced independent study courses focus on the knowledge learned in earlier courses and provide the opportunity to conduct original research in a specific field. For those in other majors who wish to explore the science of chemistry, the Chemistry Department offers courses that introduce the fundamentals of chemistry in a context designed to provide students with an enriching understanding of our natural world.

Computers and computation are pervasive in our society. They play enormously important roles in areas as diverse as education, business, industry, and the arts. The **Computer Science** Department seeks to provide students with an understanding of the nature of computation and the ability to explore the great potential of computers. The Department recognizes that students' interests in computer science vary widely, and attempts to meet these varying interests through 1) its major program, 2) a selection of courses intended for those who are interested primarily in an introduction to computer science, and 3) recommended course sequences for the non-major who wants a more extensive introduction to computer science in general or who seeks to develop some specific expertise in computing for application in some other discipline.

The computer science major equips students to pursue a wide variety of career opportunities. It can be used as preparation for a career in computing, for graduate school, or to provide important background for the student whose future career will extend outside of computer science.

The first course for majors and others intending to take more than a single computer science course is Introduction to Computer Science (CSCI 134). Upper-level courses include computer organization, algorithm design and analysis, principles of programming languages, computer networks, digital design, digital media revolution, distributed systems, advanced algorithms, theory of computation, computer graphics, computer security, human computer interaction, artificial intelligence, machine learning, operating systems, and compiler design. For those students interested in learning more about important new ideas and developments in computer science, but who are not necessarily interested in developing extensive programming skills, the department offers two courses. The Socio-Techno Web (CSCI 102) introduces many fundamental concepts in computer science by examining the social aspects of computing, and The Art and Science of Computer Graphics (CSCI 109) introduces students to the techniques of computer graphics.

Geosciences majors develop an understanding of the solid Earth and its fluid envelopes, including its physical and biological evolution and how it might change in the future. Internal forces shape mountain ranges and ocean basins. Waves, rivers, glaciers and wind sculpt the surface of the Earth, generating the landscapes all around us. Fossils entombed in sedimentary rocks supply the evidence for life's origins and evolution, and record Earth's changing climates. Introductory courses open to all students include Introduction to Weather and Climate (GEOS 100); The Co-Evolution of Earth and Life (GEOS 101); An Unfinished Planet (GEOS 102); Global Warming and Natural Disasters (GEOS 103); Oceanography (GEOS 104); and Astrobiology (GEOS 107).

Geosciences courses provide the foundation for a professional career in the earth sciences, a background for economic pursuits such as the marketing of energy or mineral resources, or simply an appreciation of our human heritage and physical environment as part of a liberal arts education. Students may choose electives to focus in depth in a particular field: for example, students with life-science interests may choose courses concentrating on geobiological topics; those interested in the dynamic solid Earth may elect courses dealing with structure and tectonics; we also have a suite of climate related courses, in addition to ones that are environmentally themed. Most of our courses are accessible to both majors and non-majors.

The **Mathematics** major is designed to meet four learning objectives: (1) Learn central ideas of mathematics and mathematical thinking, (2) Improve problem solving ability by combining creative, critical, and abstract thinking with rigorous reasoning, (3) Communicate mathematical ideas effectively, both orally and in writing, to technical and non-technical audiences, and (4) Be exposed to the power of mathematics and mathematical thinking in applications, research, and beyond.

The **Statistics** major is designed to meet four learning objectives as well: (1) Understand the central ideas of statistical thinking and data science, (2) Develop problem-solving abilities by working with real data, using them to make informed decisions and conclusions, (3) Increase interdisciplinary skills by applying statistical methods to an application area of interest and understanding the limits of statistical modeling, and (4) Communicate the results of statistical analyses to both technical and non-technical audiences. Both majors include participation in the undergraduate colloquium and opportunities for original research. Majors typically go on in mathematics, statistics, economics, other sciences, engineering, law, medicine, business, finance, consulting, teaching, and other careers.

The Program in **Neuroscience** consists of five courses including an introductory course, three electives, and a senior course. In addition, students are required to take two courses, Biology 101 and Psychology 101, as part of the program. Neuroscience (Neuroscience 201) is the basic course and provides the background for other neuroscience courses. Ideally, this will be taken in the sophomore year. Either Biology 101 or Psychology 101 serves as the prerequisite. Electives are designed to provide in depth coverage including laboratory experience in specific areas of neuroscience. At least one elective course is required from among those cross-listed in Biology (Group A) and at least one is required from among those cross-listed in Psychology (Group B). The third elective course may also come from Group A or Group B, or may be selected from other neuroscience related courses upon approval of the advisory committee. The senior course, Topics in Neuroscience (NSCI 401) is designed to provide an integrative culminating experience.

The **Physics** Department offers two majors, the standard physics major and, in cooperation with the Astronomy department, an astrophysics major. Either route serves as preparation for further work in pure or applied physics, astronomy, other sciences, engineering, medical research, science teaching and writing, and other careers requiring insight into the fundamental principles of nature. Physics students experiment with the phenomena by which the physical world is known, and the mathematical techniques and theories that make sense of it. They become well-grounded in the fundamentals of the discipline: classical mechanics, electrodynamics, optics, statistical mechanics, and quantum mechanics. We offer a variety of summer research opportunities in theoretical and experimental physics, and invite interested students at all stages of their Williams careers to participate. Physics offers several tutorial courses each year, and nearly all of our majors take more than one. Many Physics majors do senior honors projects, in which the student works individually with a faculty member in either experimental or theoretical research.

The **Psychology** Department offers a wide variety of curricular and research opportunities for both major and non-major students. Courses are grouped into the areas of behavioral neuroscience, cognitive psychology, developmental psychology, social psychology, clinical psychology, and psychology of education. After completing Introductory Psychology (PSYC 101), majors take Research Methods and Statistics (PSYC 201), in which they learn the tools used to generate knowledge in psychology, and at least three 200-level courses, which are comprehensive surveys of each of the subfields. They then take the 300-level courses, which are advanced seminars. Many of these 300-level courses are lab courses in which students do an original empirical research study; others are discussion seminars, and some are also tutorials or writing intensive courses. In each, the professors expose students to their specialty areas in depth, and students read and discuss primary literature. The major sequence ends with a 400-level discussion-oriented senior seminar. A variety of research opportunities are offered in the Psychology Department through research assistantships, independent study, senior thesis work, and the Summer Science Program.

The psychology major provides an opportunity for liberal arts students to consider the nature of mind and behavior from different perspectives. It provides sound preparation for graduate study in both academic and professional fields of psychology and is relevant to careers in education, business, law, medicine and health, and numerous others. In addition to the psychology major curriculum, our students often become concentrators in related programs across the college including Cognitive Science, Justice and Law, Public Health, and Neuroscience.

Our goal is for our students to develop each of the following skills:

- Ability to generate hypotheses, to design methodologically sound research, and to collect, analyze, and interpret data
- Critically read and interpret scientific articles
- Think critically about psychological theory, data and ideas
- Develop the ability to integrate scientific literature with observations and experiences in the real world
- Acquire knowledge of major theories, concepts, and findings in multiple sub-disciplines of psychology

- Learn to write well, including but not limited to scientific writing
- Learn to talk about psychology with others in formal and informal settings (give scientific presentations, engage in discussion and debate about ideas, research, and applications)

The latest external review of the department concluded the following: “The Department of Psychology at Williams College offers its students an exceptional undergraduate experience. Students are taught by professors who are productive, important scholars with strong commitments to teaching, and they have rich opportunities to work alongside faculty doing serious research. Faculty are generous mentors to their students; the students with whom we met sang the praises of the department as a whole. The Department has access to a good number of resources that support faculty teaching and scholarship, and the faculty are eager to continue to grow as researchers in a changing field.”

Winter Study 2020

Winter study gives students an opportunity between semesters to learn something outside of their typical studies. Options can be quite eclectic or can be be used as an introduction to research in a scientific discipline. While the science departments often sponsor outside instructors to teach on a wide variety of non-science topics, many opportunities exist to expand a students scientific literacy.

In an other casualty of the COVID-19 pandemic, Winter Study was cancelled for the 2020-21 academic year. We are very much looking forward to continuing this important tradition in January 2022.

Two of the five original art pieces adorning the walls of the new Wachenheim Science Center from artist Mike Glier (the Alexander Falck Class of 1899 professor of Art). On the left is *Horns of Mint* and on the right *The Hearts of Cattle.*

THE SCIENCE CENTER

The departments within the science center are: Astronomy, Biology, Chemistry, Computer Science, Geosciences, Mathematics and Statistics, Physics, and Psychology departments and also the interdisciplinary programs in Astrophysics, Biochemistry and Molecular Biology (BiMo), Environmental Studies (CES), and Neuroscience. The science departments are proud of our history of interdisciplinary interaction. This interaction is facilitated through the sharing of core research equipment and services; through interdepartmental programs; and, to a great extent, by the physical intermingling of faculty with common interests regardless of their departmental affiliation. Several Science Center activities further promote this by specifically encouraging discourse among scientists at Williams. This is carried out in a number of ways, including informal faculty colloquia at Tuesday lunches (during both the summer and academic year), the maintenance of a weekly science calendar, the annual publication of this *Report of Science at Williams*, and faculty lectures sponsored each semester by the local Sigma Xi chapter.

The science buildings at Williams have undergone extensive changes over the past several years. This effort was finally completed in the spring of 2021 with the completion of the *Wachenheim Science Center*. The disruption to our work during this time has been worth it since nearly every science department has has their facilities upgraded, renovated or even completely replaced by this very ambitious project. We expect these new buildings to serve us well in the decades to come.

In May, 2018, large parts of the Biology, Chemistry and Physics departments moved into what was at the time referred to as the South Science Building. That uninspired name has now been replaced with its new name *The Hopper Science Center*, named after the glacial cirque which is a signature geological feature of Mount Greylock and which is visible from the building to the south.

In early 2021, first the Geosciences department followed soon by the Psychology and Mathematics/Statistis departments moved into the new *Wachenheim Science Center* building on the site of the former *Bronfman Science Center*. The new building also houses several new modern classrooms and a beautiful auditorium which is has appropriately been named the *Bronfman Auditorium*.

The new buildings are attached to the Thompson Labs buildings, the Morley Science Labs, and the Schow Science Library via bridges. This allows us to continue the tradition of collaborative work and engagement within and among the various departments that has been a hallmark of the sciences at Williams for over five decades.

Clark Hall, the traditional home of the Geosciences department, is now empty. The fate of Clark Hall has not yet been determined, but in the short term it will continue to be used for classroom space and temporary office space while the college weighs its options for this historic building.

The construction of the two new buildings allowed us to engage in reorganization within the original science buildings. The rapidly expanding Computer Science department now occupies most of the space on the top floor of all three Thompson lab buildings.

The Williams College science departments are extremely fortunate to have secured sustainable funding for equipment through generous gifts from a number of benefactors notably including the Kresge and Keck Foundations, and the Alden Trust. These gifts allow the science center to maintain a suite of state of the art instrumentation which is shared by all departments. The equipment is maintained by a group of dedicated technical professionals in several departments: Nate Cook in the Chemistry department, Kevin Forkey in Physics, CJ Gillig in Psychology, Jay Racela in the Center for Environmental Studies, Brad Wakoff in Geosciences, and Audrey Werner in Biology. Nancy Piatczyc manages the *Oberndorf Family Microscopy Suite* in The Hopper, and Kevin Flaherty maintains our telescopes including our large 24 inch reflector on the roof of the Thompson Physics Building. Finally, Michael Taylor and Jason Mativi provide incredibly important support for all departments in our shops (wood, metal, electronics and print fabrication) allowing us to repair, maintain and design creative solutions to many issues that arise.

In the past year, we have used our funds to acquire new instrumentation in support of our research and teaching efforts. This year we purchased a new Bruker AutoFlex MALDI-TOF mass spec to replace and greatly upgrade our old MicroFlex. Through a generous gift from the family of a recent student, we have also recently upgraded our CNC mill in the shop which is expected to greatly improve its capabilities.

-Norman Bell, Editor

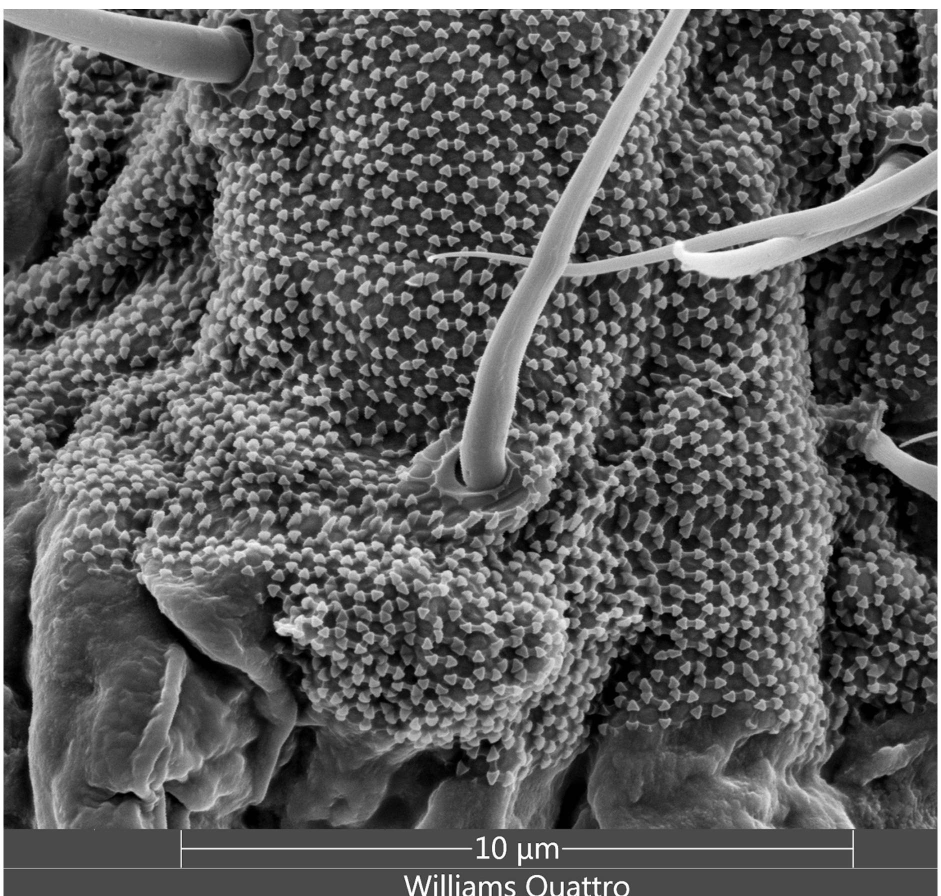
MICROSCOPY

The Oberndorf Family Microscopy Suite in The Hopper Science Center supports diverse research from labs primarily in the Biology, Chemistry, Geosciences and Physics departments. The core equipment in the facility, all of which have been replaced with upgraded instruments since The Hopper opened in May of 2018 include a JEOL JEM1400 transmission electron microscope, a Thermo Fisher (FEI) Quattro S field emission scanning electron microscope, and a Nikon A1R HD resonant scanning confocal microscope. These powerful instruments along with support instrumentation and other microscopes in the facility allow researchers to collect advanced images and elemental analysis of samples which is critical to their work.

This year, the microscopy suite supported the following research and teaching efforts in the sciences:

Biology research	Edwards, Dean, Chen, and Lebestky labs
Chemistry research	Park lab
Chemistry teaching	Principles of Modern Chemistry (CHEM 155), Advanced Chemical Concepts (CHEM 256), Instrumental Methods Analysis (CHEM 364)
Geosciences research	Cohen, Cook, amd Wobus labs,
Geosciences teaching	Astrobiology (GEOS/ASTR 107), Minerology (GEOS 202)
Physics research	Kealhofer amd Jensen labs
Neuroscience research	Marvin lab

Visit the Report of Science entries from these labs to learn more about the work being done.



Scanning electron microograph of the surface features of an unidentified springtail imaged by a student in the Instrumental Methods Analysis (CHEM 365) class from a sample of vermiculture compost.

Science Lunch Colloquia

Science Lunch provides an opportunity for the science faculty and other invited speakers to meet and present their current research to the larger science community. This is especially important for new faculty to introduce their work to people, often for the first time. In normal times, faculty met on Tusday for lunch and a short ~30 minute presentation.

Due to the global COVID-19 pandemic, science lunches were cancelled after the college decided to shut down in mid-March 2020. When in-person classes resumed in the Fall of 2020, we determined that the risk was still too great to have in-person science lunches, which historically are very well attended and are often "standing-room-only".

In an effort to replace some of the value of the Science Lunch experience, faculty presented their talk this year in an online meeting format. This was not quite the engaging experience that we had come to value in pre-pandemic times, but it seved as a worthy placeholder until we can return to meeting again in-person. We are hopeful that improving health conditions in 2022 will allow us return to in-person Tuesday lunch meetings once again.

The following virtual colloquia were presented during the 2020-21 academic year.

Date	Presenter	Title of Presentation
9/22/2020	Tiku, Majumder, Physics	Welcome and Introductions
10/20/2020	Damian Turner, Biology	Immunological memory and respiratory infections
10/27/2020	Victor Cazares, Psychology	Failure in memory encoding leads to an emotional bias
11/3/2020	Steve Swoap (Bio), Lucie Schmidt (Econ), Noah Sandstrom (Psych)	WEPO -- how can it work for Div III students?
11/10/2020	Alice Bradley, Geosciences	Seismic detection of sea ice collisions in the coastal Arctic
11/17/2020	Laurie Hetherington, Psychology	Lean Back?: Do women students still downplay their academic achievement?
4/27/20201	Phoebe Cohen, Geosciences	URGE: Unlearning Racism in the Geosciences - lessons learned and a plan for the future

In Memoriam

In 2021, we lost a treasured member of Williams science faculty with the death of Psychology Professor Emeritus Phebe Cramer on April 2. Phebe joined the faculty in 1970 as only the fifth woman on the faculty campus-wide and the first in the Psychology department. She went on to teach for nearly four decades and remained an extremely productive researcher and author well after her retirement in 2009. Her loss is keenly felt. A much more complete description of Phebe's remarkable career can be found at:

https://psychology.williams.edu/welcome-to-psychology-at-williams/news-newsletter/phebe-cramer/

Summer Science Research

Normally the summer is a relaxed, yet focused time for research, without the competition of course work to interrupt collaborative efforts between students and faculty. Summer science research (SSR) at Williams College is one of, if not the most important times of the year. Students from all science disciplines conduct focused research work under the tutelage of a faculty advisor. This research is often used as a springboard to their thesis research. We have been able to offer full time, paid research positions for typically nine weeks every summer for the past several decades.

In the Summer of 2021 we had some good news. Due to the very low infection rate in the region and the availability of highly effective vaccines, we were able to offer a nearly normal SSR experience for 216 students, an increase of 8 from 2020 and another new record. Precautions were not thrown to the wind however. Feeling that is is still not safe to congregate in large groups, we cancelled the Tuesday pizza lunch and colloquia series. Instead, we encouraged individual departments and labs to find innovative ways to engage students in smaller groups. Similarly, we decided to forego the end of Summer poster series. We very much hope to bring these programs back in 2022.

In the summer of 2021, we returned to the previous compensation model for students. Most students worked for the full 9 week period for which they were paid $4365. Rates for students who worked only a portion of the summer were pro-rated. In addition to college funds, funding for our students comes from generous grants from a many foundations, institutions and individual donors as detailed in subsequent pages. The science community and the students who receive the grants are grateful to all of the donors for the generous support.

This summer, we continued to receive support from the Henry Luce Foundation through the Claire Booth Luce Scholorship for Women in Science. This award is for sophomore women majoring in one of the six physical science disciplines (Astronomy, Chemistry, Computer Science, Geosciences, Mathematics/Statistics or Physics). In addition to their summer stipends, Clare Boothe Luce Scholars were each granted $1,100 for research materials. Normally this fund also covers conference expenses, but COVID-19 made that unnecessary. The summer research program also includes students from outside Williams. Students from a number of other institutions were sponsored by an NSF/REU site grant to the mathematics and statistics department.

Phebe Cramer: 1935-2021

2021 SSR Funding

Contributors	Number of Stipends Supported
1966 Grant Science Summer Research	4
Alison Davis resaerch Fellowship	4
Arnold Bernhard Foundation Summer Fellows Program	54
Bronfman Science Center Fund	10
Class of 1951	6
Freeman Foote Fund	3
Grant Science Research Fellow	6
Louis 1950 Summer Science Research Fellowship	3
Lowe 1940 Summer Science Research Fellows	6
Lowe JA III 1973 Chemistry Fellowship	18
Markgraf JH 1952 Fellowships	6
Marsha Altshuler Discretionary Fund for Biology	1
NASA (Astronomy)	6
NSF/NIH grants to individual faculty	32
Edward N. Perry '68 and Cynthia W. Wood Summer Science Research	1
SMALL	11
Somers B&L 1948 Physics Internships	2
Sperry Family (Geosciences)	6
Wege-Markgraf Chemistry Fellowships	11
Whitehead Scholars Program (Biology)	4
Williams Bicentennial Psychology Scholarship	1
Williams Science Center Funding	26
Williams Summer Science Program	20
Total Students Supported*	**244**

* Some students received partial support from more than one fund.

2020 SSR Advisors and Students

Advisor	Student
Astronomy	
Kevin Flaherty	Peter Knowlton
	Sammy Sasaki
Anne Jaskot	Noor Alsairafi
	Michael Arena
	Abby Kinney
	Tasan Smith-Gandy
Jay Pasachoff	Felix Klitzke
Biology	
Sonya Auer	Emily Agreda
	Julia Pham
Lois Banta	Madiha Irshad
	Irfa Qureshi
Ron Bassar	Eliza Jansujwicz
	Daniel Yuan
Pei-Wen Chen	Maki Yoshimura
Derek Dean	Emily Kondo
	Huy Pham
Joan Edwards	Mikayla Kappes
	Darren Wang
Allison Gill	Molly Fraser
	Patrick Hodgson
	Dan Lee
Cynthia Holland	Rebecca Brody
	Miriam Li
	Hisham Tadfie
Tim Lebestky	Nicole Alvarez
	Grant Gattuso
	Minjun Kim
David Loehlin	Ria Kedia
	Junhee Lee
	Georgia McClain
	Elise Root
Luana Maroja	Declan Houlihan
	Jo Kim
	Edward Lee
	Jaeeun Lee
	Neal Nevyn
Manuel Morales	Chase Cohen
	Dara Etienne
Claire Ting	Kiersten Campbell
	Chloe Heiting
Damian Turner	Genevieve Gerard
	William Spollen
	VanNashlee Ya
Heather Williams	Yewon Jung
	Marlon Stanfield-Pazmiño
Vincent van der Vinne	Katie Friedman
	Zoe Kaegi
	Ashley Xu
Center for Environmental Studies	
Jay Racela	Angela Chen
Chemistry	
Anthony Carasquillo	Siri Bohacek
	Andrew Hallwood-Driemer
	Jacob Silberman
	Benjamin Telicki
	Kathryn Wright
Amy Gehring	Kaiz Esmail
	Chloe Hysore
	Christie Yang
Christopher Goh	Lili Au
	Jose Guzman
	Joey Hua-Phan
	Curtis Liu
	Alexa Roldan
	Kathryn Wright
Sarah Goh	Angelica Pena
	Marcelo Mazariego
Kerry-Ann Green	Esther Kim
	Shreyas Rajesh
	David Yoo
Katie Hart	Devin Biesbrock
	Elise Kuwaye
	Sonya Lee
	Megalan Tso
Lee Park	Justin Connell
	Tong Gao

Lee Park	Christiana Park
	Xiaoyi Zhang
Bob Rawle	Tasnim Anika
	Olivia Graceffa
	Eunice Kim
	Amy Lam
Thomas Smith	Will Bock
	Matthew Long
	Laurel Swanson
	Nick Whitcomb
Jay Thoman	Marika Massey-Bierma
Anne Skinner	Cooper Stuntz
Ben Thuronyi	Michelle Laker
	Nawon Lee
	Odysseas Morgan
	Madeline Ohl
	Aspen Pierson
	Delaney Soble
Amanda Turek	Samuel Liu
	Harrison Toll

Computer Science

Duane Bailey	Atlas Yilmaz
Daniel Barowy	Hugo Hua
	Petros Markopoulos
Iris Howley	Hannah Ahn
	Josephine Chai
	Mira Sneirson
Bill Jannen	Kary Chen
	Brian Kamau
	Derek Rosario
	Ruby Teklemariam
Samuel McCauley	Jackson Bibbens
Kelly Shaw	Alexandra Bonat
	Alexander Joshua
Shikha Singh	Jackson Ehrenworth
	Max Enis
	David Lee
Aaron Williams	Emma Caruso
	Lindsey Chu
	Jonathan Rogers
	Elijah Washington

Geosciences

Alice Bradley	Martina Berrutti Bartesaghi
	Andrew Brito
	Kennedy Lange
Phoebe Cohen	Gwyn Chilcoat
	Mariana Hernandez
	Ashlyn Oh
	Roman Ruiz
José Constantine	Ruby Bagwyn
	Caroline Douglas
	Sylvain Fosiy
	Isaac Freitas-Eagan
	Berenize Garcia Nueva
	Austin Huang
	Jacob Jampel
Mea Cook	Dayana Manrique
Ronadh Cox	Amalia Culpepper-Wehr
	Hannah Jackson
	Devon Parfait
Lisa Gilbert	Annabel Flatland

Mathematics and Statistics

Colin Adams	Liza Jacoby
Eva Goedhart	Brian Crane
	Brian Ha
Leo Goldmakher	Jonathan Geller
	William Johnson
Pamela Harris	Peter Hollander
	Maria Rodriguez Hertz
Steven Miller	Benjamin Baily
	Justine Dell
	Teresa Dunn
	Irfan Durmic
	Henry Fleischmann
	Hongyi Hu
	Faye Jackson
	Simran Khunger
	Rene Mijares
	Arian Nadjimzadah
	Ethan Pesikoff
	Luke Reifenberg
	Alexander Shashkov
	Alicia Smith Reina

Steven Miller	Stephen Willis
	Yingzi Yang
Ralph Morrison	Lisa Cenek
	Liz Ferguson
	Eyobel Gebre
	Cassandra Marcussen
	Jason Meintjes
	Elizabeth Ostermeyer
	Shefali Ramakrishna
Shaoyang Ning	Franklin Reilly
Elizabeth Upton	Daniel Lee
	Alan Sun

Neuroscience

Victor Cazares	Nikitah Gaju
	Johanna Huarachi
	Quan Ng
	Emma Schulman
Martha Marvin	Tracy Geng
	Jason Ha
	Caitlyn Joyce

Physics

Daniel Aalberts	Brendan Hall
	Isaac Wilkins
Charlie Doret	Bless Bah Awazi
	Timothy Chang
	Renee DePencier Pinero
	Aidan Ryan
Graham Giovanetti	Ryan Gross
	Rafay Kazmi
	Tim Saffold
	William Zhang
Kate Jensen	Ethan Cooper
Kate Jensen	Sonya Dutton
	Caroline Tally
	Rose Tchuenkam
Catherine Kealhofer	Katie Brockmeyer
	Da-Yeon Koh
	Joshua Reynolds
	Benny Weng
Tiku Majumder	Russell Blakey
	Charlotte Jones
	Robin Wang
Henrik Ronellenfitsch	Adam Dionne
	Sherwood Martineau
Fred Strauch	Ryan Watson
David Tucker-Smith	Justin Berman
	Maurice Kim
	Filip Niewinski

Psychology

Jeremy Cone	Keyly Barrios Morales
	Sam Mermin
	Nikita Srivastava
	Cailin Stollar
Eliza Congdon	Gabriela Kovarsky Rotta
	Karla Mercedes
	Maria Tews
Steven Fein	Sana Jawa
	Sarah McGinn
Amie Hane	Ginger Atwood
	Julia Mariani
	Amy Martinez
Shivon Robinson	Nat Davidson
	Caitlin Han
	Cynthia Masese
Noah Sandstrom	Kiara Tan

SUMMER SCIENCE PROGRAM

The Summer Science Program (SSP) provides an enriching and intensive experience for incoming Williams students who are excited about Science, Technology, Engineering, and Mathematics (STEM) fields and who are from groups historically underrepresented in the sciences and/or who are first-generation college students. In its thirty-fourth summer in 2021, twenty-two students participated.

The program is designed to help incoming students by facilitating their transition to Williams College, developing knowledge and competencies for academic success in supportive learning environments, providing platforms for a greater sense of belonging to STEM fields and increased self-efficacy and by introducing research opportunities and supporting students in their research endeavors. Each cohort starts with a 5-week residential pre-frosh program where we preview the Williams experience by immersing participants in intensive introductory courses and introducing them to life as a Williams student. This year we offered introductory courses in Biology (Prof. Matt Carter), Chemistry (Profs. Amy Gehring, Sarah Goh and Chris Goh), Mathematics (Profs. Mihai Stoiciu, and Lori Pedersen), and a Critical Reading and Writing course (Prof. Cassandra Cleghorn). Our program's focus is on building a community of learners by emphasizing peer learning, establishing close student-faculty and student-staff relationships as well as introducing participants to the academic, social, cultural and mental well-being support structures the college has to offer. We offer special thanks also to the 4 upper-class tutors and fellows without whom the program could not succeed: *Mariela Cadena-Hernandez '23, Megan Groomes '24, Steven Lee '24* and *Sonia Nyarko '21*.

After the 5-week summer program, participants in SSP benefit from optional workshops and programming throughout their 4 years at Williams. Programming introduces participants to the process of conducting research, provides mechanisms for participants to gain paid laboratory research experience during the academic year and the college's summer research program, supports attendance to scientific meetings and disseminates information about diverse career opportunities with STEM+ degrees.

The Summer Science Program is supported by the Pathways for Inclusive Excellence Office. The program has been funded primarily by Williams College as part of its commitment to encourage the participation of traditionally underrepresented groups in the sciences. Special thanks go to the many science faculty, staff and students of Williams College who over the years have contributed to the success of the program and of its participants.

2021 SSP PARTICIPANTS

Student Participants

Harris Agha
Maymouna Bah
Victor Cazabal
Tiffany Felix
Quentin Funderburg
Shania Gonzalez
Emily Hidalgo
David Hwang
Ava Irons
Sara Lopez-Quintana
Estefany Lopez-Valazquez
Jason Mai
Morgan Nasir
Evelyn Qi
Issac Rivera
Jaskaran Singh
Bishesh Subba
Ellen Tounkara
Leah Williams
Serenity Young-Ferguson
Addison Zou

Student Tutors

Maria C. Hernandez
Megan Groomes
Steven Lee
Sonia Nyarko

Faculty

Chris Goh, Chem., SSP Director
Matt Carter, Biology
Cassandra Cleghorn, English
Amy Gehring, Chemistry
Sarah Goh, Chemistry
Lori Pedersen, Math
Mihai Stoiciu, Math

Summer Science Lab Program

For over twenty years Williams College Summer Science Lab has brought science alive for local elementary students. Summer Science Lab is an amazing science experience for children entering 5th or 6th grade. In groups of four, elementary students experiment with a variety of substances in Williams College laboratories. Each Lab group is guided by a Williams College undergraduate or a Mount Greylock Regional School student and investigates a variety of chemical reactions relating to solids, liquids, and gasses. Williams College chemistry professors Dave Richardson and Chip Lovett have presented chemical mysteries to the young scientists and explained, through demonstrations and experiments, the chemistry behind those mysteries.

The mission of Summer Science Lab is to get elementary students more engaged with and educated in the scientific process and how things work at the molecular level, and to help undergraduates, who are aspiring scientists and educators, understand how to teach science.

Historically, Summer Science Lab began in 1999 with funding from the Howard Hughes Medical Institute. Over the years additional support has also come from Williams College Olmsted funding. Williams College has also generously sponsored elementary student scholarships and busing to make this opportunity widely available.

This year (again), it was determined that we could not safely hold the Summer Science Lab Program due to ongoing COVID-19 concerns. This was a difficult decision to make, but we are committed to bringing this important program back to halls of Williams as soon as it is safe to do so.

Installed just outside the new Bronfman Auditorium are a set of 200 million year old Theropod dinosaur footprints. These prints were found and preserved by Gary Gaulin in 1996 in Holyoke, MA. A closeup view of one individual print can be seen on page 46.

SIGMA XI

The Williams College Sigma Xi chapter has played an active role on the Williams Campus since it was founded as the Sigma Xi Club in 1969. Sigma Xi is a national society honoring and encouraging research in science. The officers for 2020-21 were Professor Jay Pasachoff of the Astronomy Department (President), and Professor Lois Banta of the Biology Department (Secretary/Treasurer).

After an abbreviated speaker series last year, we were able to return to sponsoring two speakers for the 2020-21 school year. In the fall of 2020, Prof. Duane Bailey (Computer Science) presented a talk titled *"The Software-Hardware Dance: an Evolution"*. In the Spring of 2021 Prof. Daniel Aalberts (Physics) presented his highly relevant seminar *"Shooting the Mesenger RNA ==> mRNA Vaccine Technology"*. The lectures were each followed by lively and well-attended receptions in the Science Center Atrium.

Each year, the Williams College Sigma Xi Chapter sponsors a High School Science Award for a student at Mount Greylock Regional High School in Williamstown, MA, in recognition of a high level of motivation and accomplishment in science courses. This year the award was given to Livia Morales.

One of the primary purposes of Sigma Xi is to recognize graduating science students who have demonstrated exceptional ability and promise for further contributions to the advancement of scientific research. These students are elected as associate members of Sigma Xi and are inducted into the society at a ceremony during commencement weekend. The following table list the 71 seniors who were inducted in a ceremony during commencement week.

Abstracts of their honors research projects are presented in this report starting on page 88.

Astronomy	Carolina Martinez	Kimberly P. Hadaway	Declan Daly
Amina Diop	Chace Wyndom	Peter J. Hollander	Brendan Hall
Patricia Fofie	Patrick Zhuang	Robin S. Huang	Hyeongjin Kim
		Maria D. Rodriguez Hertz	Save Koontaweenpunya
Biology	**Computer Science**	Thomas G. Kirby	Duncan McCarthy
Kiersten Cambell	David J. Lee	Benjamin N. Kitchen	Sophia Millay
Erin Courville	Peter J. Zhao	John M. Petrucci	Gabriel Patonette
Brian Greenstein		Alex Simons	Nicholas Patino
Rollie Grinder	**Environmental Science**	Kasey E. Stern	Patrick Postec
Alexandra Grusky	Henry Newell	Akihiro Takigawa	Joshua Reynolds
Katya Khalizeva		Alexander Trevithick	Paige Robichaud
Dasol Lee	**Geosciences**	Julia J. Tucher	Matthew Roychowdhury
Elida Lopez	Michael T. Armstrong	Benjamin L. Weber	Declan Smith
Nevyn Neal	Niku R. Darafshi	Nehemiah J. Wilson	
Ben Maron	Molly F. Lohss		**Psychology**
	Dayana Manrique	**Neuroscience**	Matan S. Levine-Janach
Chemistry	Aria J. Mason	Daniel J. Hahn	Gwyneth C. Maloy
Petra Baldwin	Alex A. Quizon	Andrea Orozco	Simone R. Veale
Andrei Draguicevic			
Uriel Garcia	**Mathematics**	**Physics**	**Statistics**
Andrew Hallward-Driemeier	Cameron S. Edgar	Ilana Albert	Katrina Wheelan
Angel Ibarra	Max G. Everett	Justin Berman	Daniel J. Park
Anna Jackowski	Emil Graf	Nico Coloma-Cook	

Astronomy News

A starry night above the Williams College campus as viewed from the Thompson Physics Labs rooftop observatory. While it may make for an attractive photo, the light pollution can be somewhat problematic for using our telescopes.

Faculty of the Astronomy Department included Jay M. Pasachoff, Field Memorial Professor of Astronomy and Director of the Hopkins Observatory, and Chair; Anne Jaskot, Assistant Professor of Astronomy; and Kevin Flaherty, Lecturer in Astronomy and Observatory Supervisor. Marcos Peñaloza-Murillo, Professor Emeritus at the Universidad de los Andes, Mérida, Venezuela, and former Fulbright Fellow at Williams, was a visiting scientist remotely from Mérida, Venezuela. Continuing into 2021-2, we are arranging for Amina Diop '21 and David Sliski (Ph.D. '21 U. Penn) to also have Associate of the Hopkins Observatory status. Dozen-times visitor Marek Demianski (U. Warsaw) remained in consultation and has been re-appointed as Visiting Professor of Astronomy as of July 1, 2021.

Six students graduated from the department in 2021, all six received degrees in astrophysics. This year the Milham Prize in Astronomy was awarded to Amina Diop.

Because of COVID-19, instruction was largely remote. Dr. Flaherty met the lab students in small groups. For the history-of-astronomy course, Wayne Hammond met the students in small groups while Prof. Pasachoff was remote.

Amina Diop	Astrophysics
Patricia Fofie	Astrophysics
Duncan McCarthy	Astrophysics

Ebenezer Fitch Professor Emerita **Karen Kwitter** worked this year with longtime colleague Richard Henry of the University of Oklahoma on an invited review paper/tutorial on planetary nebulae for the *Publications of the Astronomical Society of the Pacific*. The paper will appear later this year. Also, their website *Gallery of Planetary Nebula Spectra* (tinyurl.com/63ed7tx), containing spectra, atlas information and references for 165 planetary nebulae, has now surpassed 70,000 views.

Professor **Jay Pasachoff** and his team study especially the solar corona, which in 2021 is rising out of the minimum of the solar-activity cycle (most easily seen as the sunspot cycle, http://sidc.oma.be/silso) but also affecting the shape and temperature of the solar corona and other aspects of the sun).

Pasachoff and his students continued to study their data from the Great American Eclipse of August 21, 2017 which crossed the entirety of the continental United States. Pasachoff had previously viewed the eclipse from Salem, Oregon with eight students with support from grants from the National Science Foundation, National Geographic Cociety and NASA. Images and other information about eclipse efforts past and future appear at http://totalsolareclipse.org.

Study continued with former students *Christian Lockwood ’20, Erin Meadors ‘20*, and *John Inoue ’20* on data collected at the July 2, 2019, total solar eclipse, observed from La Higuera, Chile. The current NSF (renewal) grant that supported the expedition was intended to also support the study of a December 14, 2020 total solar eclipse. This grant has now been extended to 2023. Due to COVID-19 restrictions, the intended eclipse viewing site at Las Grutas, Argentina, was inaccessible, and an alternate site was selected in Pucón, Chile. Special permission for entering Chile was arranged through the U.S. Embassy in Santiago in liaison with the Chilean Ministry of Science.

Pasachoff was unfortunately unable to travel to the eclipse due to Williams College COVID-19 travel restrictions, but Christian Lockwood, then working for NASA, was able to access the site for the eclipse with *Muzhou Lu '13* and other collaborators. Pasachoff has written up this event as well as a 2020 annular eclipse (which he also missed viewing) in Astronomy Magazine. He collaborated with NASA for press releases the day and week after the eclipse with an image from a collaboration with Wendy Carlos of New York based on observations by Andreas Möller from an Argentinian site:

Eclipse prediction -- https://www.nasa.gov/feature/goddard/2020/scientists-use-nasa-data-predict-appearance-corona-dec-14-total-solar-eclipse

Eclipse comet -- https://www.nasa.gov/feature/goddard/2020/recently-discovered-comet-seen-during-2020-total-solar-eclipse-SOHO

Pasachoff continued to collaborate with other former students for the 2019 and 2020 eclipses including *Kevin Reardon ’92* of the National Solar Observatory based in Boulder (CO) and *Daniel Seaton '01* of NOAA.

As part of the Keck Northeast Astronomy Consortium, Felix Klitzke, an exchange student from Wellesley, worked with Pasachoff in summer '21 on the flattening coefficient of the corona over the solar-activity cycle.

The December 4, 2021, total solar eclipse will be viewed from a chartered Airbus 321 flying east out of Punta Arenas, Chile to view totality soon after sunrise. *Peter Knowlton '21*, will participate along with another student from the fall Heliophysics tutorial. If plans come to fruition, Christian Lockwood and Muzhou Lu plan to be on the Antarctic continent to view to eclipse.

A repeat of the experiment performed by *Alan Wang '20* was planned for the 2020 total solar eclipse but couldn't be carried out. The original experiment was deemed unsuitable due to the position of the sun during the viewing. The next opportunities for the oscillation experiment will be in 2023 in Exmouth, Australia, and 2024 in Mexico or the United States.

Pasachoff continued as Chair of the IAU Working Group on Solar Eclipses. He maintains a website (assisted by *Edwin Carpio ’21*) at http://eclipses.info which provides links to maps, safe-observing information, and other information about past, current, and future eclipses.

He has been a member of the Eclipse 2017 Task Force of the American Astronomical Society which has now been updated to Eclipse 2024 in honor of the eclipse path that will cross from Mexico through the United States. The path of totality will pass through central to northern Vermont, with Williamstown, MA experiencing an almost-but-not-quite total solar eclipse.

Pasachoff has arranged a symposium at the January 2022 AAS meeting for the Centennial of the Lick Observatory expedition which tested Einstein's general theory of relativity at the 1922 total eclipse.

On June 10, 2021, Pasachoff witnessed his 73rd solar solar eclipse and 19th annular eclipse. On this occasion, he observed from a Sky & Telescope chartered plane out of Minneapolis-St. Paul Airport, flying over southern Canada. This allowed photography of the annularity shortly after dawn. Images and descriptions of the solar eclipses Pasachoff has observed are available at:

http://eclipses.info = http://sites.williams.edu/eclipse/

Pasachoff continued his solar-system interest, in the long term together with MIT/Lowell-Observatory colleagues including Michael Person, Amanda Bosh, and Carlos Zuluaga as well as Southern African Astronomical Observatory colleague Amanda Sickafoose (also at MIT), on studying the atmosphere of Pluto and other objects in the outer solar solar system through the method of stellar occultations.

Pasachoff continued his collaboration with Roberta J.M. Olson, curator of drawings at the New-York Historical Society. Their book *Cosmos: The Art and Science of the Universe* discusses about three hundred works of art related to astronomy dating back to the origin of their collaboration at the Halley's Comet passage of 1985-86. During spring '21, they studied a 19th century oil painting of the Danish astronomer Georg Frederick Ursin by artist Christoffer Wilhelm Eckersberg.

Incoming Astrophysics major *Anna Tosolini '23* spent the summer of 2021 in a Research Experiences for Undergraduates (REU) program at Caltech, studying the Laser Interferometer Gravitational-wave Observatory (LIGO) work.

Pasachoff continued as Chair of the Working Group on-Solar Eclipses of the International Astronomical Union. He is a member of the Organizing Committee of the History of Astronomy commission in which he is also a member of the Johannes Kepler Working Group. He continues as U.S. National Liaison to the successor IAU commission on Education and Development. He has been added to the IAU Executive Committee Working Group for "Star Names".

Pasachoff continued as representative of the American Astronomical Society to the American Association for the Advancement of Science's Astronomy Division.

Pasachoff continues working with Donald A. Lubowich of Hofstra University on observations of interstellar deuterium, which started with cosmological observations of its fundamental “spin-flip” spectral line at a frequency/ wavelength of 327 MHz/92 cm (http://cosmicdeuterium.info). The team was assigned six hours of observing time with the IRAM (Institut de Radioastronomie Millimétrique) millimeter-wavelength radio telescope in France for August 2019 to observe deuterated molecules at wavelengths at 2 and 3 mm in gas clouds in the part of our Milky Way Galaxy. Their results were sufficient for them to receive more observing time at IRAM in June 2020. The data are under study.

For information about Williams College's eclipse and transit expeditions: http://www.eclipses.info, http://totalsolareclipse.org, and http://www.transitofvenus.info.

Pasachoff continued as President of the Williams College Sigma Xi chapter. Pasachoff continued as the Williams College representative to the NASA-sponsored Massachusetts Space Grant Consortium. With Pasachoff's sponsorship, Christian Lockwood received a $5000 Grant in Aid of Research (GIAR) from Sigma Xi for his participation in the December 14, 2020, total solar eclipse expedition in Pucón, Chile.

Pasachoff and Jay Anderson, a Canadian meteorologist, worked on the proof for the *Peterson Field Guide to Weather* for Houghton Mifflin Harcourt; it was published in August 2021. He continued as physical-science book reviewer for *The Key Reporter*, the Phi Beta Kappa newsletter and is a Fellow of the Society for Skeptical Inquiry, is on the editorial board of the Skeptical Inquirer.

He continues to supervise the activities at the Old Hopkins Observatory, which are scheduled by Astronomy Administrative Assistant Michele Rech. Planetarium shows were suspended during 2020-21 due to the ongoing COVID-19 pandemic.

Teaching remotely in the Fall of 2020, with Zoom guests from all over the world, Pasachoff (jointly with Chapin Librarian Wayne Hammond) revised his Leadership in Astronomy course (ASTR/LEAD/HSCI/STS 240). The course studies rare books in the Williams collection including original works from Copernicus, Galileo, Kepler, and Einstein.

http://chapin.williams.edu/pasachoff/checklist.html

Lecturer **Kevin Flaherty** has continued his research on the formation of planets. With data from the Atacama Large Millimeter/submillimeter Array (ALMA) in the Atacama Desert of Chile, Dr. Flaherty uses molecular line emission to constrain the turbulent motions within disks of gas and dust surrounding young stars. After completing a study looking for turbulence around three stars, the largest such sample examined in the literature using molecular line emission, he presented these results at the 237th meeting of the American Astronomical Society in January of 2021 and the Five Years After HL Tau: A new era in planet formation meeting in December of 2020.

This past year *Amina Diop ’21* completed a senior thesis using the emission from the molecules N_2H^+ and DCO^+ to examine the spatial structure of turbulence in the one system in which turbulence has been detected. She presented this research at the National Society of Black Physicists meeting in the fall of 2020 and at the 237th meeting of the American Astronomical Society in January 2021. Amina won the Beth Brown Memorial Research Prize at the NSBP meeting. *Michael Arena ’23* spent summer 2020 searching the ALMA archive for additional planet-forming disks within which turbulence could potentially be measured. In the summer of

2021, *Sammy Sasaki '24* examined a new statistical tool for extracting turbulence measurements from the data which will be applied to the data compiled by Michael Arena. The combination of work by Michael and Sammy will allow for a substantial expansion beyond the 3-5 young planetary systems in which turbulence has been observationally constrained so far.

Extending beyond turbulence, Flaherty continues his interest in the conditions of planet formation. In the summer of '21 and continuing into his thesis, *Peter Knowlton '21.5* is examining the mass budget around young close binary stars, also known as proto-Tatooine systems (after the planet in the Star Wars movies). Flaherty is also interested in the debris left over from the collisions of Pluto-sized bodies in more mature systems, and has contributed to a recently published paper on the structure of the debris disk around a nearby system.

In the Fall of '20, Flaherty and the Williams astronomy department hosted the 31st annual fall research symposium of the Keck Northeast Astronomy Consortium (KNAC). Due to COVID-19 restrictions, this became the first virtual fall symposium in the history of KNAC, and was attended by ~60 students from across the northeast. This symposium is unique in that the research presentations, both posters and talks, are given entirely by undergraduate students, including many from Williams College. *Amina Diop '21, Patricia Fofie '21, Anneliese Silveyra '21, Peter Knowlton '21.5, Michael Arena '23,* and *Noor Alsairafi '22*, as well as students from many peer institutions, gave presentations at the conference. The virtual format allowed us to invite a keynote speaker for the first time in the history of the conference. Dra. Nicole Cabrera-Salazar of Movement Consulting, a consulting firm focused on increasing equity and inclusion within the sciences, spoke on The Importance of Collective Values in Academia.

Assistant Professor **Anne Jaskot** continued her research on rare dwarf starburst galaxies, nearby galaxies that resemble galaxies from the early universe. Her research focuses on understanding "reionization," a period of time in the early universe when ultraviolet light escaped galaxies and ionized the universe's intergalactic hydrogen gas.

She is currently leading a team of 40+ international researchers in the Low-Redshift Lyman Continuum (LyC) Survey, a program that uses the Hubble Space Telescope to detect escaping ultraviolet light from 66 nearby galaxies. The survey's observations have nearly tripled the number of known nearby galaxies with escaping ionizing ultraviolet emission. The first paper from the survey was published this year, and two of the main papers from the survey will be submitted this summer, which includes *Nicole Ford '20* as co-author. This past year, *Anneliese Silveyra '21* completed an independent study using data from the LyC Survey. She explored several different statistical techniques to determine which combination of physical parameters best predicts the amount of escaping ionizing radiation. In the summer of '21, *Noor Alsairafi '22* and *Abby Kinney '24* processed new spectra for the LyC Survey to better understand the physical properties of the sample galaxies. Jaskot is also a co-investigator on an upcoming NASA CubeSat mission, SPRITE, which aims to test ultraviolet detector technology and measure escaping ionizing radiation from additional galaxies. *Tasan Smith-Gandy '24* will be using the results of the LyC Survey to find targets for the SPRITE mission this summer.

In addition to the LyC Survey, Jaskot is studying the emission from "Green Pea" galaxies, a type of galaxy that may be similar to the early galaxies that reionized the universe. For her senior thesis, *Patricia Fofie '21* processed and analyzed spectra of two Green Pea galaxies from the Apache Point Observatory in New Mexico. By analyzing the shape of the emission lines in these spectra, Fofie showed that, contrary to the prevailing explanation, supernova explosions are unlikely to be the cause of the high velocity gas motions seen in these galaxies. *Michael Arena '23* also studyied Green Pea galaxies in Summer '21. He analyzed new UV spectra of the galaxies from the Hubble Space Telescope and compared their carbon emission features to models and to carbon emission observed in galaxies in the early universe.

Jaskot looks forward to learning more about the universe through new studies with the Hubble Space Telescope (HST) and forthcoming James Webb Space Telescope (JWST). She was recently awarded time to use the JWST to study the ionizing spectra of metal-poor galaxies and was a co-investigator on three additional successful proposals. This summer, she served as a panelist for the HST Telescope Allocation Committee, where she reviewed and recommended proposals submitted for telescope time on Hubble.

This year, Jaskot taught Introduction to Astrophysics (ASTR 111), The Nature of the Universe (ASTR 330) for non-majors, and the tutorial Between the Stars: The Interstellar Medium (ASTR 402).

Post-Graduate Plans of Astronomy Majors

Amina Diop	Ph.D. program in astrophysics at University of Virginia
Patrica Fofie	Data Analyst position at Large Millimeter Telescope, UMass, then graduate school
Save Koontaweepunya	Ph.D. program in Astronomy at Boston University

Astronomy Colloquia

On-campus colloquia are held jointly with the Physics Department. See Physics colloquia on pp. 85-86 for listings.

Off-Campus Astronomy Colloquia

Jay M. Pasachoff

“Williams College’s Hopkins Observatory”
Beyond Space, via Zoom January 2021

“Annular and Solar Eclipses”
Franklin Institute, via Zoom June 2021

“Solar Eclipses”
Harvard ‘63, via Zoom June 2021

Anne Jaskot

“Illuminating Reionization with the Low-Redshift Lyman Continuum Survey”
University of Texas Austin Astronomy Colloquium, Austin, TX (remote), September 2020

“Illuminating Reionization with the Low-Redshift Lyman Continuum Survey”
Goddard Space Flight Center Astrophysics Science Division Colloquium, Greenbelt, MD (remote), April 2021

Biology News

Dogwood flowers (*Cornus florida*)

Working closely with several interdisciplinary programs on campus, including the Biochemistry/Molecular Biology (BIMO) Program, the Neuroscience Program, the Environmental Studies Program, the Bioinformatics/Genomics/Proteomics Program and the Public Health Program, the Biology Department's goal is to provide students with the opportunity to do hands on, individual research with a professor in addition to offering state of the art academic courses. To this end, the department had 27 honors students working in faculty labs this past year and 11 of these students were inducted into the Sigma Xi Honor Society.

For the academic year 2021-22, twenty five 25 students will be conducting honors research in Biology. The department is committed to providing a positive research and learning experience for all biology students. Several of our students were awarded grants or fellowships to pursue their studies after graduation or research this summer. *Kiersten Campbell '21* and *Katya Khalizeva '21* received Stratton Fellowships for graduate work leading to a Ph.D. The department also had approximately 44 students doing summer research this year. Whitehead Fellows *Sofia Neaher '22, Raphael Rakosi-Schmidt '23, Alina Luchyshyn '23* and *Elizabeth Kwon '23* worked at either the Whitehead Institute, the Broad Institute, or the Dana-Farber Cancer Institute in Summer '21.

Funding for on-campus summer research comes from various sources including individual research grants and Division funding. At least half of the biology faculty members receive research funding from The National Science Foundation or the National Institute of Health. In addition to providing summer research stipends and covering research supply expenses, external grants and College funding allows many students to travel to professional meetings throughout the year and provides students opportunities to present their Williams research as posters or oral presentations.

Each year at graduation, the Biology Department presents awards to their outstanding seniors. *Manting Xu* and *Erin Courville* each received the Benedict Prize in Biology. *Alexandra Grusky* received the Dwight Botanical Prize. *Ben Maron* received the Conant-Harrington

Prize for exemplary performance in the biology major, and *Emily Sun* received the William C. Grant, Jr. Prize for demonstrating excellence in a broad range of areas in biology.

This year we were delighted to welcome Allison Gill as a new Assistant Professor in Biology.

Professor **Lois Banta** continued her research on the soil bacterium *Agrobacterium tumefaciens*. This plant pathogen is best known for its unique ability to deliver DNA and proteins to host plant cells, thus stably altering the genetic makeup of the plant and causing crown gall tumors ("plant cancer") to form at the infection site. One major goal of the lab's current research is to characterize the host defense responses elicited by the bacterium. This year, Honors students *Rachel Cross '21* and *Surabhi Iyer '21* were joined by Independent Study student *Georgia McClain '22* in pursuing this line of investigation. *Sofia Neaher '22* also contributed to the lab's research during the academic year, and all four students, along with *Amy Wang '23* and Biology Department Instructor Janis Bravo participated in the lab's remote literature-based journal club during the summer of 2020.

During the academic year, Professor Banta served as Biology Department Chair. She taught Biology 101 and a 200-level tutorial on Infectious Disease in the Fall, and a lab-intensive 300-level course in Integrative Bioinformatics, Genomics and Proteomics (BiGP) in the Spring. Professor Banta gave an invited talk entitled *From Research Labs to Shots in Arms: What goes into developing a vaccination strategy?* as part of the Williams College Faculty Club Lecture series. She served on the Advisory Committees for Public Health, Biochemistry/Molecular Biology, and Bioinformatics/Genomics/Proteomics. Finally, she continued as Secretary/Treasurer of the Williams College Chapter of the national scientific research honor society, Sigma Xi.

Assistant Professor **Ron Bassar** was on leave for the 2020-21 academic year. This year he continued to work on the evolution of species coexistence grant from NSF that funds short and long term research at his study site on the Caribbean island of Trinidad (www.theguppyproject.weebly.com). He was also awarded a new NSF grant, "The Evolution of Fluctuation-Dependent Species Coexistence", to take the research in a new direction. Bassar published four papers in the last year in both theoretical and empirical ecology and evolution. He continues to serve as Associate Editor for the *Journal of Animal Ecology.*

Associate Professor **Matt Carter** taught Neural Systems and Circuits (BIOL 311) in Fall 2020 and Physiology (BIOL 205) in the Spring. Outside of the classroom, he continued his research into the neural basis of food intake and sleep behaviors using mice as a model organism. His research is funded by a grant from the National Institutes of Health (#DK105510) and National Science Foundation (#1652060). During the past year, he wrote *Designing Science Presentations, 2nd Ed.*, published by Academic Press (Elsevier).

During the past academic year, Professor Carter worked with three thesis students. *Faris Gulamali '21* completed a thesis project titled: "Effects of sleep state on AgRP neuron activity in food deprived mice." *Kenny Han '21* completed a thesis project titled: "Effect of food accessibility on activity in Tac1 PSTN neurons" *Sarah Willwerth '21* completed a thesis project titled: "Effects of sleep state on AgRP neuron activity."

Senior Lecturer **Derek Dean** has continued to teach and develop labs for The Organism (BIOL102) and Genetics (BIOL 202). Despite the challenges of COVID-19, Dean, along with Lab Instructors Janis Bravo and Deborah Carlisle and department technicians Audrey Werner and Debra Rogers-Gillig, were able to offer in-person intro labs this past year. Remote labs were also offered for those unable to be on campus. This was all done with minimal sacrifice of learning goals. The experience led to the development of some new tools such as posting prelab lectures online so students can review the material while preparing lab reports. This will continue to be offered in future couses as well.

In his research lab, Dean uses the fruit fly *Drosophila* as a model to study seizure disorders. His thesis students *Cassie Deshong '21* and *Juan Peticco '21* made some compelling findings about neuronal types and interacting genes responsible for seizure sensitivity in flies. On another research topic, *Alvin Pacheco-Omaña '21* has likely mapped the latest "Fly Lab" mutant to its gene: Ocellularless (Oce), an interesting mutant trait which causes the light-sensing ocelli on the top of the fly head to have abnormal structure. The mutant trait was described in the 1950s, but its gene had not previously been identified. Dean, along with Professors David Loehlin and Lois Banta, and Professor David Deitcher of Cornell published the education article *Mapping a mutation to its gene: The "fly lab* as a modern research experience. CourseSource. https://doi.org/10.24918/cs.2020.51. It is a free, open access Genetics lesson plan that simulates primary research for the students and provides comprehensive guidance for educators who have not worked with flies before.

Professor **Joan Edwards** remotely taught The Tropics: Biology and Social Issues (BIOL 134) in the fall and she was on leave in Spring ‘21.

She continues her research on pollinator networks. During the spring and summer of 2020, she worked with *Ally Grusky ‘21* and *Elise Kuwaye ‘23* to study the pollinators of spring ephemeral flowers in New England’s mixed hemlock hardwood forests. Ally used these data in her senior honors thesis to visualize the spring ephemeral pollination network.

Edwards also continued with her study of experimental plots near the weather station in Hopkins Forest where she is studying how different mowing regimens affect floral resources for pollinators. The focus of this study is on fall blooming members of the *Asteraceae*, which provide important resources for pollinators just prior to the onset of winter. Professor Edwards also continues with her study of the invasive plant, *Alliaria petiolata* (garlic mustard), where she has tracked populations in early, mid and late successional forests since 1998. Professor Edwards and Visiting Professor Sonya Auer co-advised *Henry Newell ‘21* for his honors thesis. He used the 22-year garlic mustard dataset to link plant demographics to environmental variables.

Professor Edwards gave two invited talks this year. See the list of Biology colloquia for more information.

Assistant Professor **Allison Gill** taught Ecology (BIOL/ENVI 203) in Fall 2020, which was adapted to accommodate COVID-19 friendly labs and a hybrid teaching model, as well as the new advanced seminar Forests of the Future – Understanding Global Change (BIOL 428) which investigates changes to forest ecosystems in a warming and CO_2 enriched world.

During summer 2020, she advised remote research projects in collaboration with *Rollie Grinder ’21*, I*sabel Lane ’21,* and *Crystal Ma ’21*. Isabel completed a thesis titled “A soil and microbial characterization of two sites in Hopkins Memorial Forest” and Crystal Ma completed a thesis titled “Evaluating the role of fungal guild interactions in litter metabolism, soil organic matter formation, and the soil carbon response to nitrogen fertilization’. Rollie Grinder extended her summer research evaluating the relationship between soil nitrification and carbon availability across US Long Term Ecological Research sites into an independent study in fall 2020, in collaboration with Professor Ashley Keiser at the UMass Amherst Stockbridge School of Agriculture. Prof. Gill and Assistant Professor José Constantine (Geoscience) co-advised *Michael Armstrong's ‘21* Geoscience thesis ‘Biophysical controls on tidal channel dynamics on the Plum Island Estuary’. Gill continued her collaboration with Professor Mea Cook (Geoscience), Jay Racela (Environmental Studies), and Drew Jones (Environmental Studies) monitoring seasonal patterns of carbon, nitrogen, and oxygen isotope chemistry in the Birch Brook watershed in Hopkins Memorial Forest. She published a paper in *Ecology Letters* titled "Experimental nitrogen fertilization globally accelerates, then slows decomposition of leaf litter".

Assistant Professor **David Loehlin** and his students continued research into evolution and the genetic mechanisms of how genes are expressed. The lab continues to research an exciting problem: genes that are duplicated in tandem often do not produce twice the RNA and protein as single-copy genes. We know basically nothing about how this happens, making this an exciting new area for students to explore. The lab uses the fruit fly *Drosophila* to study gene structure, function, and evolution in living animals, and a variety of cutting-edge genetic tools including CRISPR and MoClo.

The lab was awarded a $180k, 3-year grant from the National Institutes of Health in September which provides material support for research materials and (especially) summer student research stipends. Professor Loehlin presented a talk at the Boston Area *Drosophila* Meeting in June 2020, titled “Regulatory mutations play the major role in the evolution of gene activity”.

Lab members this year included *Catherine Powell ’22, Junhee Lee ’24* and *Ria Kedia ‘24*. Past student contributors include *Jesse Ames ’18, Jeremiah Kim '18, Kyung Shin Kang '19, George Yacoub '21, Hafidh Hassan ‘21, Caleigh Paster ‘21, Manting Xu ‘21,* and *VanNashlee Ya ‘22.*

Professor **Luana Maroja** continued her research on speciation working primarily with crickets and fruit flies. She was awarded a new NSF grant in collaboration with colleagues at the University of Denver, CO. She taught Genetics (BIOL 202) in the Fall and Evolution (BIOL 305) in the Spring and advised one thesis student, *Nevyn Neal ’21*. She published one paper looking at cranial asymmetries in natural populations of water rats from Brazil and the relationship of inbreeding and stress in generating these asymmetries.

In the Fall of 2020 Professor **Heather Williams** taught the Sensory Biology (NSCI 312) course with independent lab projects designed by students. The course was taught in two sections, one in-person and one remote. Professor Williams also taught in-person and remote sections of The Organism (BIOL 102) in the Spring of 2021.

Research on the cultural evolution and syntax of the songs of birds in wild populations continued, and the lab published two papers: one reported on how interactions with neighbors shapes song learning and another reviewed the mechanisms that result in the cultural evolution of songs.

The Biology Department continued to participate in the Class of 1960 Scholars program.

Post-Graduate Plans of Biology Majors

Name	Plans
Alexander, Mazie	Undecided
Baldree, Sarah	Patient Care Coordinator, CCRM Fertility Boston, Newton, MA
Bourne, Brianna	Undecided
Campbell, Kiersten	NIH Postbac IRTA Fellow, Bioinformatics & Scientific Programming Core at National Institute of Child Health and Human Development (NICHD), Bethesda MD
Carpio, Edwin	Taking a gap year and then matriculating into Medical School for 2022.
Conza, Adrienne	Dermatology Assistant, Skinbar MD by Vibrant Dermatology, Dedham MA
Courville, Erin	MPhil in Translational Biomedical Research at the University of Cambridge
Cross, Rachel	Clinical Research Coordinator at Massachusetts General Hospital under an Orthopedic Hand and Wrist surgeon
Dauk, Morgan	Research Assistant, Department of Orthopedic Surgery Operations at the University of Utah, Salt Lake City, UT
Davenport, Holly	Undecided
Deshong, Cassie	Consulting, ClearView Healthcare Partners, Newton, MA
Gill, Gursajan	Research Technician, Owen Lab @ Stanford Medical School
Goldberg, Elijah	Undecided
Goldman, Erinn	Analyst at Clearview Healthcare Partners (Life Sciences Consulting)
Greenstein, Brian	Undecided
Grinder, Rollie	PhD at the University of Arizona Ecology and Evolutionary Biology program
Grusky, Alexandra	Undecided
Han, Kenneth	M.D. at University of Southern California
Harden, Kalina	Undecided
Hem, Jessica	Laboratory Research Technician, Mullally Lab, Brigham and Woman's Hospital, Boston, MA
Hooker Newball, Del	MPH at Brown
Hurwitz, Maddie	MD, University of Virginia
Ith, Izabelle	Clinical Research Assistant at Boston Children's Hospital
Iyer, Surabhi	Clinical Research Coordinator, Medical Practice Evaluation Center, Massachusetts General Hospital,
Keller, Fiona	Undecided
Khalizeva, Katya	PhD in Biology, MIT
Laino, Victoria	Undecided

Lane, Isabelle	Undecided
Lee, Dasol	Undecided
Levitt, Sarah	Research Assistant at Princeton University (while applying to medical school)
Lopez, Elida	Undecided
Lum, Jacob	Undecided
Ma, Crystal	Undecided
Madsen, Amanda	I am starting a Pre-Health Post-Baccalaureate program at the University of Pennsylvania in the Fall of 2021.
Maloy, Gwyneth	MD candidate, Yale School of Medicine
Maron, Ben	Firefighter/EMT
Martin, Gabrielle	Undecided
Morley-McLaughlin, Theresa	Undecided
Neal, Nevyn	Graduate school at University of Tennessee
Nyarko, Sonia	MPhil in American History at the University of Cambridge, Emmanuel College
Orozco, Andrea	Research Assistant, Harvard School of Dental Medicine, Boston, MA
Pacheco-Omana, Alvin	Undecided
Paster, Caleigh O.	Assistant Account Executive, Porter Novelli Health Team, New York, NY
Peticco, Juan P.	NIH Predoctoral Research Fellow, Massachusetts General Hospital, Boston, MA
Ramirez, Juliana L.	MD at University of Michigan School of Medicine
Rana, Marya Z.	MPhil in Population Health Sciences, University of Cambridge
Rebolledo, Juan C.	Undecided
Rodriguez, Claudia	Undecided
Shim, Jane	Clinical Research Coordinator, Massachusetts General Hospital, Boston, MA
St. Juste, Mariane S.	Lab Project Coordinator at Northeastern University in Boston, MA
Sun, Emily C.	Undecided
Tran, Daniel H.	Fulbright Scholar, Paris, France
Veale, Simone R.	Research Assistant at the Psychiatry Nuroimaging Laboratory at BWH/HMS
Villegas, Fernando R.	Undecided
Williams, Blaine T.	Undecided
Willwerth, Sarah B.	Clinical Research Assistant in Orthopedics/Sports Medicine, Boston Children's Hospital
Xu, Manting	MD at the University of Louisville School of Medicine
Yacoub, George E.	Technical Solutions Engineer, Epic Systems, Madison, WI
Yu, Guanghao	Clinical Research Coordinator, Boston Medical Center, Boston, MA

Biology Colloquia

Rose Abramoff, LSCE (Laboratoire des Sciences du Climat et de l'Environnement) in France
"Microbes, minerals, and math: Mechanisms of soil C sequestration, the models used to make predictions, and their role in understanding global climate change"

Lois Banta,
"From Research Labs to Shots in Arms: What goes into developing a vaccination strategy?"
Faculty Club Lecture series, Williams College

Joan Edwards, co-presented with Wendy Hybl Fannin as part of an Art and Wellness Workshop Series
"Cures for Strange Times: Foraging and Flowers,"
Williams College Museum of Art. 21 January 2021

Jon Penterman, a Senior Scientist at CRISPR Therapeutics
"Genomic analysis in CRISPR gene editing therapies"

Petra Levin '89, Washington University in St. Louis
"Starvation induces shrinkage of the bacterial cytoplasm"

Sue Rhee, Carnegie Institute
"Understanding Mechanisms of Thermoadaptation in a Desert Extremophile Tidestromia Oblongifolia"

Gautam Dantas, Washington University School of Medicine
"Predicting and Combating Biotic and Abiotic Disruptions to Diverse Microbiomes"

Britt Glaunsinger, UC Berkeley
"How the pandemic coronavirus restricts cellular gene expression"

Off-Campus Biology Colloquia

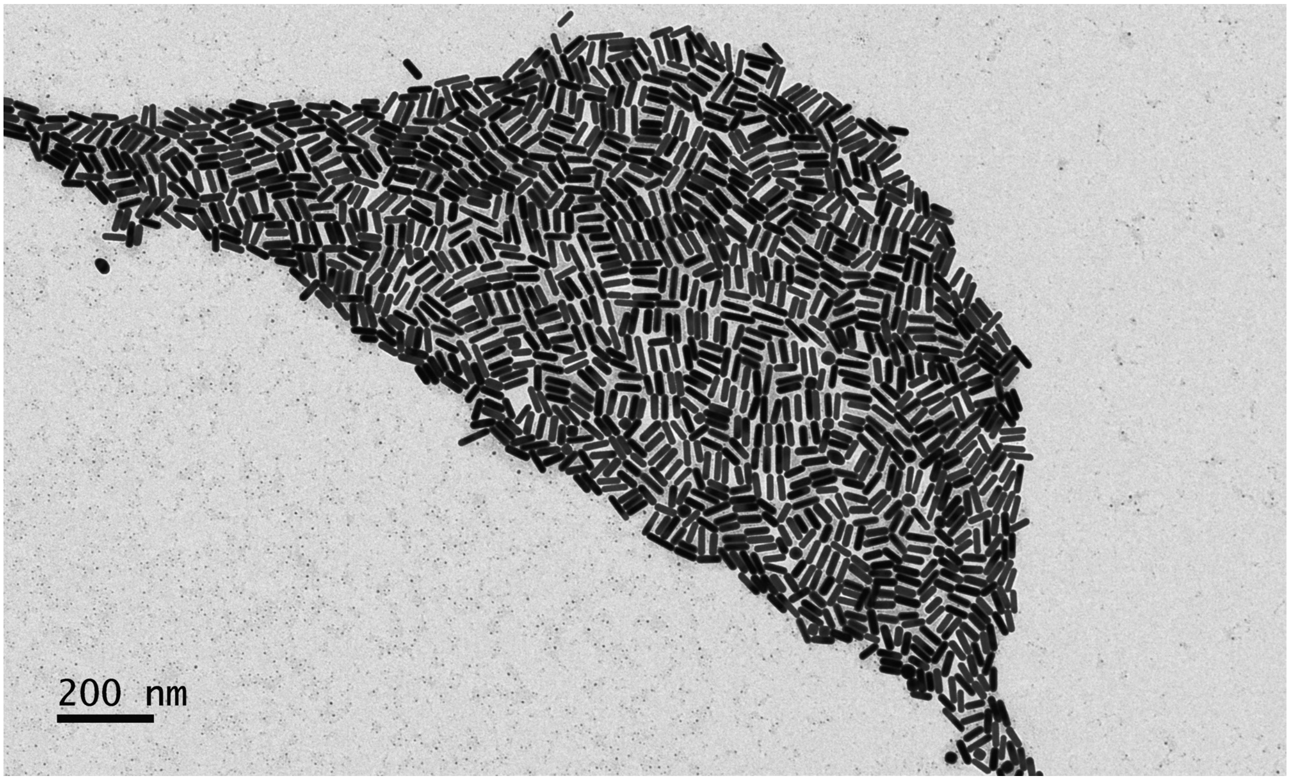
Ron Bassar
"Intraguild predation and cannibalism drives species coexistence in Trinidadian streams"
Annual Meeting of the American Naturalist Society. Asilomar, California

Allison Gill
"Experimental nitrogen fertilization globally accelerates, then slows decomposition of leaf litter"
Annual Meeting of the Ecological Society of America. Virtual presentation during COVID-19

David Loehlin
"Regulatory mutations play the major role in the evolution of gene activity"
Virtual talk at the Boston Area Drosophila Meeting in June 2020

Joan Edwards
"Conserving Our Flowers and their Pollinators in the Midst of the Sixth Extinction"
Williamstown Garden Club. 14 November 2020

Chemistry News



Transmission electron micrograph of gold nanoparticles produced in the lab of Professor Lee Park. Each rod shaped nanoparticle is approximately 350 Au atomic nuclei long and contains just a few thousand atoms. Micrograph captured by *Xiaoyi Zhang '23* and *Justin Connell '22*.

As the world drastically adjusted to the realities of the COVID-19 pandemic during the spring of 2020, the Chemistry Department was no different. What was initially scheduled to be spring break, the faculty and staff were in limbo with the ever-changing events that devastated so many.

The department, as well as the entire campus, transformed their way of educating and living day-to-day without losing the high standards and expectations of Williams College. We spent the summer converting our curriculum to a new hybrid format and reimagining laboratory experiments. The words “zoom”, “remote”, the “new normal”, and “can you hear me” were in our daily conversations. But as the year progressed, faculty, staff, and students kept their heads high and our elevated goals were accomplished.

We were pleased to welcome two new members to the Chemistry Department in July 2020. Assistant Professor Kerry-Ann Green, in an unusual first year, began by teaching Inorganic/Organometallic Chemistry (CHEM 335) in the fall and Introductory Organic Chemistry (CHEM 156) in the spring. Amnon Ortoll-Bloch joined us for a two-year post-doctoral position supported by the Consortium for Faculty Diversity. Amnon taught Instrumental Methods of Analysis (CHEM 364) in the fall and The Science Behind Materials (CHEM 114) in the spring. His research focuses on the crystallization of inorganic materials in catalysis.

Two other new additions to the Chemistry Department are our Instagram feed (williams_chemistry) and the creation of a departmental DEI committee. This year, we included a training session for teaching assistants, initiated by students and led by the Davis Center. Our conversations focused on pedagogy and the student experience, as one step towards assessing and improving departmental culture.

In 2021, we had 28 graduating senior chemistry majors, with 16 completing senior theses under the guidance of faculty. As always, we awarded a number of prizes to our graduating seniors and other students:

Award Name	Honoree
John Sabin Adriance prize for outstanding work throughout their chemistry career	Wyndom Chace ’21
James F. Skinner prize for distinguished achievement in chemistry	Andrew Hallward-Driemeier ‘21
Leverett Mears prize in recognition of strength in chemistry and future in medical career	Maddie Hurwitz ‘21
ACS Connecticut Valley Section Award	Faris Gulamali ‘21
American Institute of Chemists Award	Patrick Zhuang ‘21
ACS Division of Organic Chemistry Award	Uriel Garcia ‘21
ACS Division of Inorganic Chemistry Award	Marcelo Mazariego ‘22
ACS Division of Physical Chemistry Award	Carolina Martinez ‘21
ACS Division of Analytical Chemistry Award	Ben Telicki ‘22
Warren Prize	Samuel Liu ’23 Madeline Ohl ‘23
CHEM 151 Introductory Chemistry Achievement Award	Eriks Zamurs ‘24
CHEM 153 Raymond Chang Achievement Award	Ria Kedia ’24, Brooke Krivickas ’24
CHEM 155 Introductory Chemistry Achievement Award	Ethan Jeon ‘23

We also continued to participate in the Chemistry Class of 1960 Scholars Program. This year’s speaker were Professor Neil Garg from UCLA and Professor Desiree Plata from MIT. As part of this program, the students participate by attending a preliminary meeting with a Chemistry Department faculty member to discuss some of the research papers by the seminar speaker, attend the seminar/discussion, and then are given an opportunity for further discussion with the visiting scientist at an informal reception or dinner.

Class of 1960 Scholars in Chemistry

Jaya Alagar	Paul Leclerc
Ginger Atwood	Irfa Qureshi
Cloe Heiting	Shreyas Rajesh
Huijun Huang	Brian Valladares
Maya Huffman	David Yeh

Finally, in the summer of 2021, we had 46 students doing summer research in faculty labs. Funding for these research students comes from individual research grants as support from the J.A. Lowe III ’73 summer research fund, the J. Hodge Markgraf ’52 Summer Research Fund, the Wege-Markgraf Fund, and Summer Science Program funds.

Assistant Professor **Anthony Carrasquillo** returned to the department in July 2020 as an environmental/physical/analytical chemist. In the fall he taught the new course Environmental Organic Chemistry (CHEM/ENVI 373) which introduces students to the ways we can quantitatively predict the fate and lifetime of organic compounds in the environment. In the spring he taught the lectures and laboratory for Thermodynamics and Statistical Mechanics (CHEM 366) to 18 students.

Carrasquillo is an atmospheric organic photochemist. His research focuses on improving our understanding of how solid or liquid particulate matter (aerosol particles) form and chemically evolve in the atmosphere. He has four projects that examine the reactivity of organic molecules in three distinct atmospheric media: gas, organic aerosol, and aqueous phase. Thesis student *Andrew Hallward-Driemeier ’21* finished the work that he started during his first year at Williams, investigating the role of functional group identity in the formation of organic aerosol from gas-phase oxidation reactions. Thesis student *Wyndom Chace ’21* began a new project seeking to characterize the chemical composition of the aerosol produced from the oxidation of limonene, a common hydrocarbon responsible for the scent of lemons. This work will be continued this summer by rising thesis student *Ben Telicki ’22*. Ben completed an independent study in the Spring optimizing aerosol collection from our environmental chamber into liquid solvents for analysis with GC- and LC-MS. Our third project involves measuring the rate constants for the photochemical degradation of the tannin proxy gallic acid in aqueous media. Work study students *Abby Matheny ’22, Siri Bohacek ’22,* and *Jacob Silberman ’23* worked together to optimize the reaction conditions for the production of the OH radical and determined the rate constant for its reaction with gallic acid. Our fourth project in collaboration with Rebecca LaLonde of Reed College investigates the stability and reactivity of biogenically derived hydroxynitrates within aerosol particles. *Petra Baldwin '21* completed an independent study in the Fall which was continued by *Kathryn Wright '22* in the Spring semester. They measured the rate of hydroxynitrate decay using a new NMR-based kinetics approach. The manuscript for this initial work has been submitted for publication and the second project involving a new class of hydroynitrates and conditions will be examined starting this summer. While this was a challenging year for all, Carrasquillo is proud of the work that his group was able to accomplish and looks forward to returning to the lab full time in the Fall during his sabbatical.

Carrasquillo also served as a reviewer for the journals *Environmental Science: Processes and Impacts*, *Atmospheric Chemistry and Physics*, and *Environmental Science* and as a grant reviewer for the *National Science Foundation.*

Professor **Amy Gehring** taught in the department's biochemistry curriculum this year. She also continued her research program, working alongside a talented group of students. This was an especially challenging year, with the COVID-19 pandemic upending many aspects of both teaching and research. Nonetheless, these disruptions gave Gehring the opportunity to broadly reevaluate her teaching and to try some new approaches. In the fall, Gehring taught Biochemistry I: Structure and Function of Biological Molecules (CHEM/BIOL/BIMO 321) to students both on-campus and to those studying remotely. She developed a series of in-class activities that could be deployed with both in-person and off-campus students, and which aimed to maximize precious time for classroom interaction. In the spring, she taught the capstone seminar for the BIMO concentration, Topics in Biochemistry and Molecular Biology (BIMO 401). For the first time, she taught this course as a tutorial as opposed to a seminar, which was another valuable and eye-opening teaching experience.

Despite the necessary laboratory time and occupancy restrictions, Gehring was thrilled to have the opportunity to mentor an enthusiastic group of students over the course of the academic year. The lab continued research which works to define the biochemical and genetic features of secondary metabolism and development in the antibiotic-producing soil bacteria genus: *Streptomyces*. This large bacterial genus is well-known for its biosynthesis of molecules with important applications in medicine (*e.g*. antibiotics).

One research area focused on the post-translational modification of the antibiotic biosynthetic machinery, examining both the enzymes that install this required modification and those that remove it. Senior thesis student *Angel Ibarra '21* studied several phosphopantetheinyl transferase enzymes from the industrially-important organism *Streptomyces avermitilis*. Senior thesis student *Steve Menjivar '21* pursued the complementary project to study phosphodiesterase activity from *S. avermitilis* and using substrate proteins involved in biosynthesis of the important anti-parasitic drug ivermectin. Senior thesis student *George Yacoub '21* studied the interplay of primary metabolism and secondary metabolism (such as for the biosynthesis of antibiotics) in *Streptomyces coelicolor* using LCMS. All three thesis projects yielded exciting results that have provided many directions for future work. Six work study students also continued their projects from the previous academic year: *Kaiz Esmail '23, Chloe Hysore '23, Elise Kuwaye '23, AbuBakr Sangare '23, Laurel Swanson '23,* and *Christie Yang '23*. It has been a pleasure to watch their enthusiasm and talents for research continue to grow! Finally, we were joined in the spring semester by Physics Department thesis student *Brendan Hall '21* from the Aalberts lab, as he tested in the wet lab some of his computational predictions concerning gene expression in *Escherichia coli*. A challenging year to say the least, but research efforts in the Gehring lab didn't miss a beat given the dedication and resourcefulness of these undergraduate students.

Professor **Christopher Goh** co-taught Instrumental Methods of Analysis (CHEM 364) with Postdoctoral Fellow Amnon Ortoll-Bloch in the fall semester, and the tutorial Bioinorganic Chemistry: Metals in Living Systems (CHEM 338T). He also continued his work as a Faculty Fellow in the Office of Institutional Diversity and the Davis Center and as Director of the Summer Science Program. Despite the COVID-19 restrictions, we were able to create a close classroom community. *Andrei Draguicevic '21* joined the laboratory as a senior thesis student and continued the research on small molecule models of metal-binding polymers for environmental remediation. He was joined on this project by Ortoll-Bloch, *Mohammad Faizaan '23, Curtis Liu '23,* and *Alexa Roldan '23.* Also this year, *Lili Au '22, Ruby Navarro '24* and *Christiana Park '22* started a project to examine the metal-binding in carminic-acid based pigments. This work stemmed from one of the lab projects in instrumental methods of analysis course. The group did an amazing job under the circumstances.

In a year like no other, nothing was business as usual for Professor **Sarah Goh** and her students. The summer of 2020 saw no students on campus, and so *Vanessa Quevedo Barrios '21* and *Kevin Garcia Rios '22* started their senior thesis exploration over Zoom, with paper discussions, NMR practice, and some self-reflection of what they were looking for in a thesis project. Jumping off of the findings of *Julie Ha '20*, Vanessa's thesis focused on making cationic polymers for antibacterial applications. With research time limited to three hour shifts and no more than three students at a time, Vanessa perfected the art of always being in the lab. She finished her year strong, demonstrating that more hydrophobic polymers inhibit, but do not retard the growth of E. coli. Kevin started his thesis in the spring semester, building from Vanessa's results and extending the antibacterial study to focus on cationic block copolymers and further increase their hydrophobicity.

Despite the occupancy limits, several other students also managed to find time to be in the lab. *Brian Valladares '22* completed an independent study on the (difficult) polymerization of hindered amino acid-based monomers. Building from *Alex Lou's '13* thesis work, Brian found that the rigid chiral center of these acrylamide monomers strongly inihibited polymerization. Independent study student *Marcelo Mazariego '22* continued the work of *Justin Ho '20* on lignin-based monomers, building degradable hydrogels from vanillin and syringealdehyde based monomers. These students were joined by *Maya Huffman '22* and *Caroline Broude '22*. In the summer of '21, Marcelo was joined by *Angelica Pena '24*. Marcelo continued his hydrogel research, and Angelica examined copolymerization kinetics. Next year, the lab will be once again a bustling hub of activity, with Kevin finishing his thesis in December, Marcelo, Maya, and *Taylor McClennan '22* beginning their thesis work, along with a several independent and work study students. Throughout this year, the students were stellar collaborators. Not knowing how the year would go, we were all a little surprised at how many experiments we could get done with some creative timing and teamwork. They were all amazing!!

Sarah co-taught Introductory Chemistry (CHEM 151) in the fall of 2020 along with Professor Katie Hart. Presented in a flipped classroom format. With lectures by Hart taped and watched ahead of time, it freed up class time to be focused on problem solving. Taking the remote section, Sarah was nervous to teach to a screen. The students were fabulous! Despite being in different corners of the world, they jumped into discussions and found ways to effectively and efficiently collaborate across time zones. Demonstrations didn't work quite so well over Zoom, but that's an improvement for another year. In the spring of 2021, Sarah taught three sections of Introductory Organic Chemistry (CHEM 156), co-teaching with Professor Kerry-Ann Green. The remote option continued to be a collection of collaborators, and the in person sections enjoyed a three-dimensional instructor. (It did make learning 3D shapes and sterics a bit more facile.) The biggest bonus of this year was the small class sizes, making it easier to read the room and work through problems in class at a comfortable pace.

Assistant Professor **Kerry-Ann Green** joined the Chemistry Department in July 2020. She taught Inorganic/Organometallic Chemistry (CHEM 335) in the fall and Organic Chemistry I (CHEM 156) in the spring. The Green lab is located in the Hopper Science Center and her research interests lie at the interface of organic and inorganic chemistry. She and her cohort of research students explore the synthesis of first row transition metal catalysts and their application to organic synthesis. *Chulwoo Kim '21* completed honors thesis research focused on building up a library of structurally diverse carbon-donor ligand precursors for use in the synthesis of various catalysts. During the 2020-21 academic year she also mentored research assistants *Claudia Zhang '24, Hannah Matthew '23* and *David Yoo '24*. She advised *Esther Kim '23, Shreyas Rajesh '23* and *David Yoo '24* for the summer 2021 research program, exploring the synthesis of some nickel-based catalysts for cross-coupling reactions as well as on the development of a microwave-assisted synthesis of some ligand precursors.

Assistant Professor **Katie Hart** taught Introductory Chemistry (CHEM 151) in the fall and Biochemistry I (BIOL/CHEM/BIMO 321) in the spring. She mentored two independent study students, *Megalan Tso '22* and *Sonya Lee '22*, and one research assistant, *Devin Biesbrock '23*. She also continued as a board member for the BioBuilder Foundation, consulting on how best to train the next generation of bioengineers and synthetic biologists.

The Hart lab studies how drug resistance evolves at the molecular level with a particular focus on protein stability. Many forms of drug resistance depend upon a small number of mutations that result in changes to a protein's amino acid sequence. By investigating how these changes affect protein structure, stability and function, we can begin to understand how evolution works at the molecular level and leverage these insights to inform the design and implementation of new drug treatments. Current projects in the lab investigate drug resistant mutations in beta-lactamase, an enzyme critical for antibiotic resistance in bacteria using biophysical techniques (circular dichroism, UV-vis and fluorescence spectroscopies) and microbiology techniques (cell growth competitions, minimum inhibitory concentration measurements, screen development).

This year, Professor **Lee Park** expected to be on sabbatical, but postponed those plans due to COVID-19 restrictions. As a result, she was on campus for a year like no other (or so we hope!) Though it was a tough year all around, there were some silver linings. For example, Concepts of Chemistry (CHEM 153) is typically taught as one large lecture. But this year, it was split into 4 smaller sections, two of which Park taught in a hybrid format to approximately 35 students. Working with co-instructors Bob Rawle (who taught the other two sections) and Jen Rosenthal (who taught all of the lab sections), the lab program in the course was entirely revamped. While we were planning for the fall, we had no idea how many students would be attending in person vs remotely, nor what the constraints on laboratory work would be. As a result, we designed a lab program that relied somewhat less on the hands-on technique-based skills that we usually teach, and focused the labs instead on other equally important skills (experiment design, collaborative work) that we hoped would translate better to a range of attendance modes. Lab kits were mailed to students attending remotely and worked hard to keep them as engaged as possible with their in-person labmates (Jen Rosenthal deserves the bulk of the credit for the design and implementation of the lab program).

While not every aspect of the course redesign will be necessary under more normal circumstances, the experience has gotten us thinking more broadly about the ways that we normally teach. In the spring, Park taught a new non-majors course Roses are Red; the Chemical and Physical Origins of Color (CHEM 117). This is a course that Park had been hoping to teach at various moments over the years, but was never able to find room for in her teaching responsibilities. But since she wasn't supposed to be on campus at all in 2020-21, she was finally able to mount this course, which is another silver lining for the year. The course was great fun, and included a lab program and visits to many of the resources on and near campus (WCMA, Special Collections, The Clark Art Institute, and Mass MoCA), as well as guest lectures by colleagues from philosophy, Studio Art, Art History, Biology, and Neuroscience.

Park did not have any research students (or even a research lab) this year. But starting in the summer of 2021, she'll get her lab up and running again, with 4 summer students. In work outside the department, she continued her work for the American Chemical Society Petroleum Research Fund Standing Panel for Materials Science.

During the 2020-21 academic year, Professor **Enrique Peacock-López** taught the lectures and two lab sections of Current Topics in Chemistry (CHEM 155). In this course, Peacock-López considered a novel approach to chemical dynamics, which includes regulatory mechanisms in enzyme kinetics.

The work at distance continued early in 2020, with *Will Bock '22*, who analyzed chiral oscillations and spontaneous mirror symmetry breaking in a simple polymerization model. Mr. Bock's findings have been published in the journal *Symmetry*. A second student, *Laney Soble '23* examined the role of Rev in the regulation of HIV protein translation. Finally, *Marcelo Mazariego '22* analyzed a mechanism that yields bursting oscillations in a modified Ricker map. The results of this work have been submitted for publication in the journal *Chaos*.

During the academic year, Professor Peacock-López continued his collaboration with Ben-Gurion University, where Professor Gonen Ashkenazy's group has synthesized artificial peptide networks. In collaboration with Nathaniel Wagner, Peacock-López analyzed the smallest closed peptide network that shows bistability and oscillations under CSTR conditions. For this network, under open conditions, he characterized peptide networks and their emergent dynamic behavior.

Finally, Peacock-López served in the Reviewer Board of the journal *Entropy*, and has reviewed for the *Journal of Mathematical Chemistry; Chaos; Journal of Complexity; Mathematics; Chaos, Solitons and Fractals; Symmetry; Science Reports,* and for the *National Science Foundation*.

In his third year in the Chemistry Department, Assistant Professor **Bob Rawle** continued researching his primary interest of viruses and lipid membranes. In the fall, he taught Concepts of Chemistry (CHEM 153), to an engaged group new chemists – some remote and some in person. In the spring, he taught Biophysical Chemistry (CHEM 367) to a wonderful group of juniors and seniors in a hybrid class.

Rawle has established his research laboratory in The Hopper Science Center. His research program has 3 principal areas, all of which fall under the general field of the biophysics of lipid membranes. In the first two areas, he studies the molecular events at the heart of the initial stages of infection of all membrane-enveloped viruses – *i.e.* binding of the virus to the host cell membrane and fusion of the viral membrane with the host cell membrane. Prior to his arrival at Williams, he studied Zika virus and influenza virus. Here at Williams, he is studying viruses from the *paramyxovirus* and *flavivirus* families, both of which are responsible for substantial disease in humans and animals worldwide. He studies viral binding and fusion using both wet lab experiments and computational approaches. His third research focus is developing and applying methodologies to make bioanalytical measurements of model lipid membranes which are commonly used in basic science, drug delivery, and drug formulation applications.

This year, Rawle was excited to carry out his research with an outstanding group of Williams students, including thesis students *Papa Freduah Anderson '21* and *Ali Ladha '21*. They were joined in the lab by *Amy Lam '22, Olivia Graceffa '22, Abraham Park '22, Nandini Seetharaman '22, Eunice Kim '23, Alexis Poindexter '23,* and *Joanna Tan '23*. The students did a remarkable job collecting data in all three project areas, with many follow-up directions to pursue.

In February, Rawle virtually attended the 64th Annual Biophysical Society Meeting together with students Papa Freduah Anderson, Amy Lam, Olivia Graceffa and Abe Park. They presented three research posters relating to their studies on Sendai virus membrane binding and fusion and West Nile virus fusion, respectively.

Rawle was pleased to have a manuscript accepted for publication in *ACS Infectious Diseases* based on work done here at Williams studying West Nile virus.

Senior Lecturer Emerita **Anne Skinner** gave a talk to the Harvard Alumni Association in April on early human migration to Europe and into the Western Hemisphere.

Professor **Tom Smith** spent the fall of his twenty-third year at Williams team-teaching Intermediate Organic Chemistry (CHEM 251) with Professor Amanda Turek to 78 intrepid Williams students. With some students in-person and others remote, we traded the normal lab experience for small virtual conferences where the students and TAs worked problems together over Zoom. Smith also welcomed two new thesis students to his research program in organic synthesis and methods development in his beautiful laboratory in the Hopper Science Building. *Patrick Zhuang '21* continued Smith's grant-supported work in the area of Asymmetric Methods for the Synthesis of Pyran-Based Anticancer Natural Products. Patrick probed a new approach to a key fragment assembly in the ongoing synthesis of the marine natural product, enigmazole A. *Cody Carrier '21* continued our collaboration with the Drugs for Neglected Diseases initiative (DNDi), an international non-profit organization. Working with the open-source COVID Moonshot Project, Cody prepared a series of protease inhibitors that show promising activity against the SARS-CoV-2 virus, which still (as of this writing) lacks an effective therapeutic treatment. Smith also taught his upper-level organic synthesis course, Synthetic Organic Chemistry (CHEM 342), to fourteen hard-core chemistry majors. In place of the normal weekly lab, "Synthesis Friday" seminars gave the students a chance to dig into complex syntheses from the chemical literature and present some of the most interesting transformations to their classmates. All in all, we made the best of a very unusual year!

In the fall semester, Professor **Jay Thoman** returned to teaching in person, offering Quantum Chemistry and Chemical Dynamics (CHEM 361), with a pandemic-limited lab program. In the spring semester, Thoman taught two sections of Advanced Chemical Concepts (CHEM 256), one in person, and one hybrid.

During summer 2020, Thoman was joined remotely by *Mia Holtze '22* to analyze Hoosic River floodplain sediments collected by *Summer-Solstice Thomas '20* as part of her completed thesis in the Geosciences department. Thoman worked in the Environmental Analysis Lab, while Holtze analyzed gas chromatograms. *Abe Eafa '21* continued this work for his senior thesis project, with help from work-study students *Xiaoyi Zhang '23* and *Ziyang Shen '23*. The team of PCB researchers demonstrated the importance of oxbow lakes for pollutant storage. In a second research project, thesis student *Anna Jackowski '21* expanded regional studies of perfluorinated pollutant molecules (PFAS) to show the presence of selected PFAS molecules in addition to PFOA. Working in Vermont in summer 2020, *Marika Massey-Bierman '22.5* collected soil and pine needle samples for PFAS analysis in summer 2021. *Huijun Huang '21* continued as a work-study student on the PFAS project.

As College Marshal, Thoman helped to organize an online fall 2020 Convocation, and the ever-changing May 2021 Senior Celebration for the Williams College Class of 2021. Everyone in the Marshal's office looks forward to a similar celebration for the pandemic-impacted Class of 2020, which is now planned for July 2022. Chemistry colleague Lee Park took over as College Marshal in July 2021.

Assistant Professor **Ben Thuronyi** continued work on establishing the fast-growing bacterium *Vibrio na-*

triegens as a synthetic biology and directed evolution host organism. Thuronyi was on parental leave in fall 2020. In February 2021, they co-organized the inaugural "Vnat 2021" virtual conference, bringing together >100 participants and 22 speakers to discuss *V. natriegens* biotechnology. They taught the second iteration of Chemical and Synthetic Biology (CHEM 326), covering current topics in chemical biology and synthetic biology through immersion in primary literature, remotely during the spring semester. Work enabled by Thuronyi's postdoctoral project was published in *Nature Biotechnology* with Thuronyi as a coauthor.

During winter study and spring 2021, *Aspen Pierson '21* began her calendar year thesis studies on enhancing natural transformation of plasmids, which could make it easier to build large pools of diverse DNA for evolution experiments. Research assistants *Madeline Ohl '23* and *Michelle Laker '22* were joined by *Delaney Soble '23* and *Nawon Lee '24* in the spring, building DNA constructs to begin modifying the *V. natriegens* genome. The Thuronyi lab relocated from Hopper Science Building 101 to HSB 010 (a binary inversion) to free up the lab with existing fume hoods for Professor Green. Experimental work during the summer, with all five continuing students joined by *Odysseas Morgan '21*, replicated published natural transformation results and set the stage for extending them.

Assistant Professor **Amanda Turek** and her students had a fun and productive year in lab despite the unique challenges presented by the pandemic. Her honors thesis students, *Uriel Garcia '21* and *Carolina Martinez '21*, expanded the Turek Lab's research in exciting new directions, investigating and optimizing strategies for nucleophilic aromatic substitution reactions with aryl halides and a variety of nitrogen nucleophiles. They were joined in the lab by *Harrison Toll '22, Maria Roman '22*, *Ginger Atwood '22* and *Samuel Liu '23* Harrison and Maria each completed independent projects.

Turek had a rewarding year of teaching and innovating in the classroom teaching Intermediate Organic Chemistry (CHEM 251) in the fall semester alongside Professor Tom Smith to a group of students both remote and on campus. In the spring, she taught Physical Organic Chemistry (CHEM 344), this time with a full semester of mechanistic laboratory exercises.

Post-Graduate Plans of Chemistry Majors

Papa Freduah Anderson	Research Technician, Harvard, then medical school
Petra Baldwin	Unknown
Abigail Barrett	Unknown
Joe Bouvier	Unknown
Cody Carrier	Medical School
Wyndom Chace	Ph.D. in Atmospheric Chemistry, University of Colorado, Boulder
Rebecca Christainsen	Trader, PEAK6 Investments LLC, New York City, NY
Andrei Draguicevic	Ph.D. in Chemistry, University of Washington
Abraham Eafa	Research Technician, Dana-Farber Cancer Institute, then graduate school
Peter Fousek	M.A.R, Yale University
Jaylan Fraser-Mines	Ph.D. in Materials Science and Engineering
Michelle Garcia	Research Assistant, Oregon Health and Science University
Uriel Garcia	Ph.D. in Chemistry, University of Wisconsin-Madison
Faris Gulamali	M.D., Mt. Sinai
Kimberly Hadaway	Ph.D. in (Pure) Mathematics, Iowa State University
Andrew Hallward-Driemeier	Unknown
Maddie Hurwitz	M.D. at UVA Medical School
Angel Ibarra	Ph.D. in Chemistry, University of Wisconsin-Madison
Anna Jackowski	Environmental Specialist at Triumvirate Environmental, New York, NY
Chulwoo Kim	Research Technician, Brigham & Women's Hospital, then medical school

Ali Ladha	Boston Consulting Group, then medical school
Carolina Martinez	Ph.D. in Chemistry, Texas A&M
Steve Menjivar	Medical school
Octavio Montano	Unknown
Vanessa Quevedo	Working at Brigham and Women's Hospital, Boston, MA
Alex Quizon	Ph.D. in Earth & Environmental Sciences, University of Michigan
Karl Thomas	Unknown
Patrick Zhuang	Research Technician, Dana-Farber Cancer Institute, then medical school

Chemistry Colloquia

Tamas Benkovics, Loxo Oncology, Charles Compton Lectureship
"Innovations for the Synthesis of Diverse Nucleosides"

Neil Garg, UCLA, Class of 1960 Scholars
"Strained Intermediates and Chemical Education as Vehicles for Innovation"

Lindsey Hanson, Trinity College
"Seeing the Force: Designing and Understanding Optomechanical Sensors"

Desiree Plata, MIT, Class of 1960 Scholars
"Hydrophobic Organic Contaminants Associated with Hydraulic Fracturing: Advanced Tools for Predicting Environmental Exposure Plant Materials"

Stanislav Presolski, Yale-NUS College
"Mechanism of the Ligand-accelerated CuAAC Reaction: Practical Implications and Research Inspirations"

Off-Campus Chemistry Colloquia

Papa Freduah Anderson '21 and Robert J. Rawle
"Bulk Fusion Studies of Sendai Virus and Application of Mass Action Kinetic Fusion Model"
New England Science Symposium, 2021
Biophysical Society Annual Meeting, Virtual Meeting, 2021

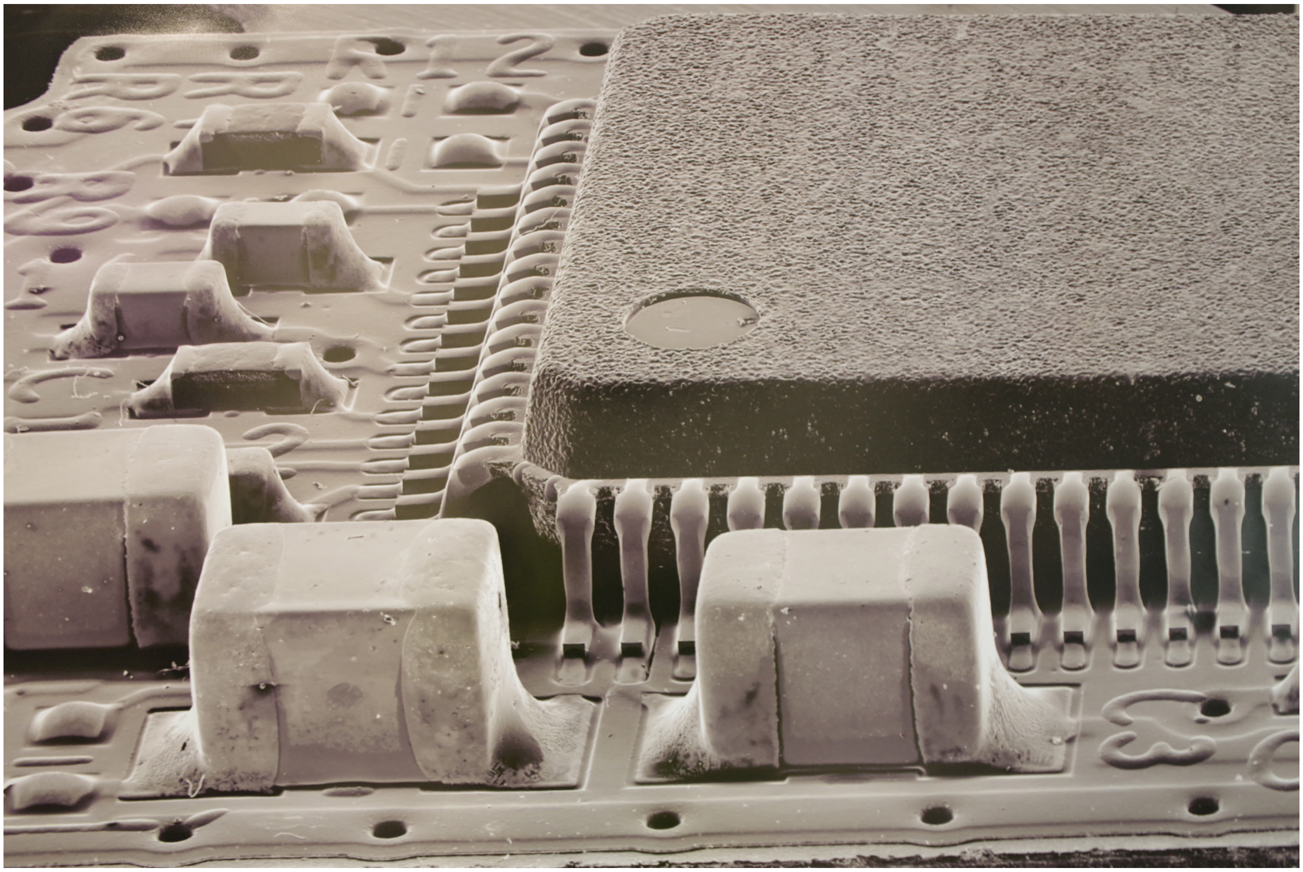
Andrew Hallward-Driemeier '21
"Impact of Functional Group Identity on SOA Yields and Kinetics"
American Association for Aerosol Research (AAAR)
Virtual Poster, October 2021

Katie Hart
"The Highs and Lows of Rraversing Energy Landscapes at a PUI"
Washington University School of Medicine, Department of Biochemistry and Molecular Biophysics, August 21, 2020

Amy Lam '22, Nandini Seetharaman '22, Eunice Kim '23, Orville Kirkland '20, and Robert J. Rawle
"Single-Virus Investigation of Non-Sialic-Acid-Mediated Sendai Virus Binding to Supported Lipid Bilayers in the Absence of Ganglioside Receptor"
Biophysical Society Annual Meeting, Virtual Meeting, 2021

Abraham Park '22, Olivia Graceffa '22, and Robert J. Rawle
"Investigation of West Nile Virus Off-Pathway Membrane Fusion Mechanisms using Kinetic Modeling"
Biophysical Society Annual Meeting, Virtual Meeting, 2021

COMPUTER SCIENCE NEWS



Scanning electron micrograph of a circuit board. Image captured by Nick Zammuto '99

Student interest in computer science remained high in 2020-2021 with 46 graduating seniors and 51 junior majors. This year the department welcomed Molly Feldman (PhD Cornell) as a Visiting Assistant Professor. While here, she taught both our introductory computer science class and an elective on "Human Work in Computational Systems." We are also delighted to welcome Rohit Bhattacharya (Johns Hopkins University) to the department as an Assistant Professor. In other staffing news, we wish Andrea Danyluk and Bill Lenhart the best as they enter retirement. We will miss them both very much.

While the COVID pandemic disrupted many departmental activities this past year, we were still able to hold several virtual events involving alumni, including a career panel featuring David Moon '16, Abbie Zimmermann-Niefield '15, Tony Liu '16, Melanie Subbiah '17, and Kenny Jones '17,

as well as a colloquium talk by Daniel Seita '14.

Several members of the department attended virtual computing conferences. Kiersten Campbell '21 attended the ACM Richard Tapia Celebration of Diversity in September. In October, Jihong Lee '22, Jennifer Lee '22, Catherine Yeh '22, Raquel Livingston '21, Madeline Burbage '22, Vy Nguyen '21, and Betsy Button '22 attended the Grace Hopper Celebration of Women in Computing. Also attending the conference were faculty members Kelly Shaw, Shikha Singh and Molly Feldman. Maddie Burbage '22 was a winner of the ACM Student Research Competition at GHC 2020, for her poster titled, "A Hardware Engine for Generating Number-Theoretic Sequences."

Three of our students earned competitive prizes in Computer Science this year: David Lee received the Goldberg Prize for his thesis presentation, and Sam Gilman and Peter Zhao received the Ward Prize for best project in Computer Science.

This year, due to the challenges of working in a pandemic, the Computer Science department did not participate in the Class of 60 Scholars program.

This year, Professor **Jeannie Albrecht** was on sabbatical. Although she had planned to continue her project involving energy monitoring and visualization in the Class of 1966 Environmental Center, the pandemic made this challenging. Motivated by the time she spent at home helping her children navigate online elementary school, she shifted her focus to developing curricular materials for teaching Computer Science and Computational Thinking to elementary-aged children. This summer, she plans to run a weeklong summer camp for 6th graders. Participants will learn how to program in Python using Lego Mindstorm robots. If successful, she hopes to expand the camp to younger children and involve college students as counselors in future years.

Assistant Professor **Daniel Barowy** continues to research ways to improve the usability, safety, and expressiveness of programming languages. Barowy was on leave during the 2020-21 academic year.

In 2020, Barowy continued his collaboration with Assistant Professor Charlie Curtsinger at Grinnell College. Their work was funded by a successful NSF grant proposal to support research into "Intelligent Developer Infrastructure." The focus of the year's work was on developing the Riker build system, which simplifies the process of constructing and distributing software. Traditional build systems require that developers write detailed "build specifications" that describe how software is to be assembled. Bugs in these specifications have consequences ranging from slow build times to flawed software. The Riker tool completely eliminates the need for programmers to write these specifications. Instead, Riker records and replays a programmer's interactions with their build environment, automatically generating precise specifications. These specifications utilize a novel predicate build calculus, also designed by Barowy and Curtsinger, called TraceIR. TraceIR guarantees that builds are always correct and always produce fast, incremental builds. Riker can build many large, real-world software projects like redis and sqlite with performance competitive with hand-tuned builds, and it is even capable of building itself. Riker is currently in submission to SOSP '21, a top operating systems conference.

With colleague Jeannie Albrecht, Barowy jointly supervised thesis research for Williams student *Markus Feng '21*. Feng's thesis explored extensions to the POSIX shell specification to support ad hoc, reliable, distributed programming. The goal of the project was to significantly lower the barrier to writing distributed programs. Feng focused his efforts on the design of a shell-like language, called Shard, that presupposes almost no configuration or user background knowledge in distributed systems. Shard simplifies distributed programs by binning applications into a small set of "application classes." Instead of forcing developers to pollute application logic with reliability-related code, Shard asks programmers to choose from a small set of pre-existing application classes. Feng's prototype demonstrated that Shard reliably and scalably expresses a wide spectrum of real-world distributed programming problems, like system orchestration or data-parallel computation. Feng successfully defended this work in the spring and was awarded high honors.

Starting in January 2021, Barowy joined the RiSE group at Microsoft Research as a Visiting Researcher, working with longtime collaborators Ben Zorn and Emery Berger (UMass Amherst). This collaboration continued prior research on the ExceLint spreadsheet bug finding algorithm. Efforts focused on algorithmic changes to meet real-world deployment criteria, like low latency (<5 ms) and actionable bug reports (e.g., "autocomplete suggestions"). Barowy also started a new line of research with Zorn on a radically different form of programming language documentation for novice spreadsheet users. This work is designed to close the skills gap between what a user knows and what they intend to do by interactively demonstrating how to use a given function in the context of a user's own program. The technology frames the problem as a kind of constraint satisfaction problem. If the constraint problem can be solved, such solutions are guaranteed to be correct and useful programming examples. Barowy concluded his Visiting Researcher position at the end of June, but these collaborations will likely continue into the next year.

In October of 2020, Barowy also presented the prior year's work on the Infrastructor system (co-developed with Bill Jannen) at the 2020 SPLASH-E (virtual) Symposium. This was a second opportunity to present the work, since the original conference venue, SIGCSE '20, was cancelled due to the pandemic. Finally, Barowy served as an External Reviewer for the 2020 ACM SIGPLAN International Conference on Object-Oriented Programming, Systems, Languages, and Applications (OOPSLA '20) as well as web chair for the 42nd ACM SIGPLAN International Conference on Programming Language Design and Implementation (PLDI '21).

Professor **Andrea Danyluk** continued her work in computer and data science education, as well as in diversity and inclusion in computing education and research. She was co-chair of the Association for Computing Machinery (ACM) Task Force on Data Science. The goal of this multi-year international effort was to develop recommendations for the computing-based competencies that should be part of an undergraduate degree in Data Science. The complete set of recommendations with example courses was officially approved and endorsed by the ACM Education Board in early 2021. Danyluk, along with several colleagues from the Task Force, presented the Data Science curriculum recommendations at SIGCSE, the annual ACM Symposium on Computer Science Education. Danyluk is also co-chair of the CRA-WP, the Computing Research Association's Committee on Widening Participation in Computing Research. CRA-WP continued all of its programs and started new ones despite the challenges imposed by the pandemic.

Professor **Stephen Freund**, currently serving as Computer Science chair, continues to explore ways to help programmers write more reliable and efficient multithreaded software designed to run on multicore processors. This work involves not only developing defect detection tools but also exploring scalability-oriented optimizations that enable programmers to more easily design safe and efficient code for computers with many processing cores.

Most of Freund's research effort this past year was spent on building and publishing results for the Anchor program verifier. This is a tool to verify that a concurrent program is free of errors and behaves according to its specification. This is a notoriously challenging problem that Anchor tackles through a synthesis of analysis techniques Freund and his colleagues have developed over the last decade, as well as a new programming language for writing concurrent code. This work was published in a paper titled "The Anchor Verifier for Blocking and Non-blocking Concurrent Software" at the OOPSLA Conference in November.

In addition, Freund was the General Chair for the ACM SIGPLAN International Conference on Programming Language Design and Implementation (PLDI), which was held in June 2021. PLDI is the premier forum in the field of programming languages and programming systems research, covering the areas of design, implementation, theory, applications, and performance. Over a thousand attendees participated in this six day virtual event.

Assistant Professor **Iris Howley** continued her research this summer on artificial intelligence (AI) explainability as part of her NSF grant, "Understanding Learning Analytics Algorithms in Teacher and Student Decision-Making." Machine learning and AI algorithms make assumptions and learn biases of which the users of the systems may not be aware. Empowering teachers and students to appropriately interrogate questionable output from the educational technology they use to make decisions in the classroom is an important contribution of this work. In the summer, she began work with *Kelsie Hao '21, Hannah Ahn '23,* and *Minh Phan '23* on building an explainable for two AI algorithms, Bayesian Knowledge Tracing and Deep Knowledge Tracing. Over the academic year, she continued work with *Catherine Yeh '22* identifying what it means to understand an algorithm, and how algorithmic understanding can be measured. This work was presented at an invited talk at Union College entitled, "Explaining AI for Decision Making: What we don't know won't hurt us?"

This research on AI explainables applies methods from Howley's fall and spring semester course on Human-Artificial Intelligence Interaction (CSCI 378). Other topics of this newly developed course include the history of AI winters, practical machine learning, designing for AI failure, Design Justice, AI ethics, chatbots, human-in-the-loop systems, automatically generated artwork, recommender systems, as well as large language models. HAII provides a unique opportunity for students to apply their humanities thinking from other courses to timely and relevant topics within artificial intelligence and computer science.

Assistant Professor **Bill Jannen** uses modern data structures, in particular write-optimized dictionaries, to improve storage software. He is a member of the team developing BetrFS, an in-kernel Linux file system that performs random writes, metadata operations, and directory scans orders-of-magnitude faster than conventional file systems.

With the BetrFS team, Bill has continued to tackle fundamental systems problems through a theoretician's lens. Recently, the team has been grappling with ways to translate BetrFS's very strong performance advantages on hard disk drives into similar advantages on faster storage media. Over the past year, the team has developed a series of optimizations to bridge this performance gap, including new approaches for cooperative memory management and further advancements to the state-of-the-art in range operations in key-value stores.

The team has also continued to study the problem of efficiently copying data. Duplicating large objects is so prevalent in modern computing workflows that many file systems support operations that make logical copies without making full physical copies. The article Copy-on-Abundant-Write for Nimble File System Clones, coauthored by Yang Zhan (UNC Chapel Hill), Alexander Conway (Rutgers), Yizheng Jiao (UNC Chapel Hill), Nirjhar Mukherjee (UNC Chapel Hill), Ian Groombridge (Pace), Michael A. Bender (Stony Brook), Martín Farach-Colton (Rutgers), Rob Johnson (VMware), Donald E. Porter (UNC Chapel Hill), and Jun Yuan (Pace), presented the technique "Copy on Abundant Write", and showed how to implement logical copies that are fast to create, edit, and read, all while being space-efficient.

Bill has also served on the program committees for both the USENIX Conference on File and Storage Technologies and the USENIX Annual Technical Conference.

In his final year at Williams, Professor **Bill Lenhart** continued pursuing his interests in graph drawing and computational geometry, focusing mainly on problems involving the representation of graphs and geometric objects in two and three dimensions subject to various constraints.

Current projects include joint ongoing work with Giuseppe Liotta (University of Perugia) on algorithms to compute mutual witness drawings for pairs of graphs and with Laurie Heyer (Davidson College), Ulrike Stege (U. of Victoria, BC), and Sue Whitesides (U. of Victoria, BC, emerita) on computing partitions of arrangements of cubes in 3 dimensions.

A conference paper with F. De Luca et al, Packing Trees into 1-Planar Graphs, presented at WALCOM 2020 last year, was published as a “long paper” in *WALCOM 2020: Algorithms and Computation*, a volume of the Lecture Notes in Computer Science series.

Assistant Professor **Samuel McCauley** uses algorithms to improve computational performance. He is particularly interested in randomized algorithms and has recently been working on Bloom filters and similarity search.

Recently, McCauley's interest in similarity search has focused on space-efficient approaches, where only a small amount of space is used to help efficiently search in the dataset. This is a continuation of work done last summer with *Ammar Eltigani '23* and *Petros Markopolous '23*, and is closely related to thesis work on inverting indices performed over the past year by *Peter Zhao '21*.

Recently, McCauley received a grant to continue work on space-efficient similarity search (NSF CRII: AF: RUI: New Approaches for Space-Efficient Similarity Search). This grant is focused especially on integrating undergraduates in the research and including the results in courses at Williams College.

McCauley's research on Bloom filters has largely focused on adaptivity. Bloom filters are a data structure for lossy compression---some stored data is lost in exchange for drastic space savings. This line of research focuses on adapting that loss as the data structure is used to improve performance. This past year, McCauley has been co-advising a thesis by *David J. Lee '21* with Shikha Singh, and with help from *Max Stein '21* that examines how these filters can be implemented efficiently. This work was recently accepted to be published at the European Symposium on Algorithms.

A collaborative research project this summer with *David J. Lee '21, Jackson Bibbens '22*, and Shikha Singh, will focus on learned indices: how a machine learning approach can help us efficiently store and access real-world data. This area has seen a great deal of research from a practical point of view, whereas our approach is more foundational: under what assumptions on the data can these approaches work, and how can we leverage these assumptions to give better performance?

McCauley has an ongoing project with Mert Erdemir and Rishab Nithyanand (both of the University of Iowa) on algorithms and analysis of website fingerprinting defenses. In addition, he has a project with Shay Golan, Matan Kraus, Shachar Meir, Prof. Ely Porat, and Guy Wolf (all at Bar-Ilan University) on maintaining node outdegree in low-arboricity graphs.

Over the past year, McCauley served on the program committee for the Symposium on Applied and Computational Discrete Algorithms (ACDA). In fall 2020, McCauley taught Algorithm Design and Analysis (CSCI 256). In spring 2020, Prof. McCauley taught Data Structures (CSCI 136) with William Lenhart. Both courses were taught in a hybrid model, featuring prerecorded videos as well as videotaped in-person lectures.

McCauley has had two publications accepted over the past year: Approximate Similarity Search Under Edit Distance Using Locality-Sensitive Hashing, presented at ICDT 2021, and Support Optimality and Adaptive Cuckoo Filters (joint work with Tsvi Kopelowitz and Ely Porat), at WADS 2021.

Associate Professor **Kelly Shaw** continued her research into verifying the correctness of updates to data by processors and by nodes in distributed systems, including in Internet of Things (IoT) systems. She also explored techniques for improving the performance of pattern matching applications on graphics processors.

Working with Princeton University collaborators Professor Margaret Martonosi and graduate students Themis Melissaris and Markos Markakis, Shaw completed research improving the state of the art for experimentally testing the correctness of data updates in multiprocessor systems. Their approach, called perpetual litmus tests, improves upon the concept of litmus tests, which are small tests executed repeatedly on systems to detect if data is updated in a way inconsistent with the guarantees indicated in the system specifications. Their PerpLE tool significantly speeds up litmus-based consistency testing by removing synchronization needed between each repeated execution of traditional litmus tests. They published their paper titled "PerpLE: Improving the Speed and Effectiveness of Memory Consistency Testing" at the 2020 IEEE/ACM International Symposium on Microarchitecture. Her work with collaborators Martonosi and Melissaris also explored the benefits of adapting litmus tests for use in distributed systems. They created Musli Tool, which is a framework for converting multiprocessor-based litmus tests for execution on distributed systems, and evaluated the performance and effectiveness of this approach when verifying the correctness of updates in the Cassandra distributed database.

Over the summer of 2020, Shaw worked with several students on IoT research. *Atlas Yilmaz '23* created a static analysis tool that detects if a Samsung SmartThings application may incorrectly update data based on its use of the application programming interface. *Karol Regula '22* implemented mechanisms for ensuring the correctness of updates to IoT devices in the Mozilla WebThings open source IoT platform and tested their performance overheads. *Jared Berger '21* extended the WebThings gateway to store device data into the Cassandra distributed database and evaluated the performance overheads of deploying *Will Burford's 2021* thesis work on detecting inconsistent updates when IoT data was stored in Cassandra.

Shaw also worked with *Andrew Thai '21* on his honors thesis research into improving the performance of pattern matching applications executing on graphics processors. Specifically, Thai explored whether a filtering mechanism could be used in automata processing applications to reduce the number of slow global memory requests and speed up execution.

Shaw served as general co-chair for the 2020 IEEE International Symposium on Performance Analysis of Systems and Software, which was held virtually in August 2020. She served on the program committee for the International Symposium on Computer Architecture, International Conference on Parallel Processing, and the IEEE International Symposium on Workload Characterization. She also became a member of the Computing Research Association's Education Committee (CRA-E).

Assistant Professor **Shikha Singh** continued her research in the area of algorithmic game theory, algorithms and data structures. In algorithmic game theory, her focus is on analyzing how incentives and rational behavior influence the outcome of algorithms. In algorithms, her focus is on the design of I/O-efficient, randomized and adaptive data structures.

As part of the NSF-funded project "Verifiable Computation Outsourcing: A Non-Cooperative Approach", Singh worked on designing simple and efficient payment-based mechanisms to verify the correctness of outsourced computation, where the payment directly incentivizes honest behaviour by service providers. Singh gave an invited talk on this topic at the Theory of Computing seminar at Harvard University in November 2020. Singh is collaborating with Miguel Mosteiro at Pace University to design and analyze outsourcing protocols for distributed-computing applications using a repeated games framework.

Singh is also active in the field of algorithms and data structures. She continued her long-term collaboration with researchers at Sandia National Labs on designing cache-efficient data structures to support high-throughput cyber streams. Singh completed the collaborative project 'Timely Reporting of Heavy Hitters using External Memory' (which appeared at the ACM International Conference on Management of Data (SIGMOD 2020 as an extended abstract). The full version of this work was recently accepted for publication in the journal ACM Transactions of Database Systems (TODS) with Singh as the lead author.

Singh's work on designing practical and provably adaptive filters (joint work with *David Lee '21, Max Stein '21* and Sam McCauley) was recently accepted for publication in the proceedings of the European Symposium on Algorithms (ESA 2021). This was in large part due to the excellent work done by Singh's thesis student David Lee (thesis co-advised by McCauley). Notably, David's thesis presentation also won the Sam Goldberg Colloquium Prize in Computer Science. David is continuing his research on applied algorithms this summer as a post baccalaureate researcher in Singh's lab, and will be joining Cornell University to start his PhD in Computer Science this Fall.

Singh served on several program committees during the year: Symposium on Algorithmic Engineering and Experiments (ALENEX '21), and Mathematical Foundations of Computer Science (MFCS '21), as well as an

NSF panel and is currently serving as the guest editor for a special issue of the Theoretical Computer Science journal.

Singh delivered a short demo lecture on "P vs NP" as part of a special microteaching panel organized at SIGCSE Technical Symposium on CS Education, along with five exceptional educators. At Williams, Singh taught a new elective on Algorithmic Game Theory (CS 357) in the Fall. The course focuses on the interplay between game-theoretic incentives and computation, with the overarching goal of analyzing whether selfish behaviour can or should influence system design. One of the final projects from the course titled "Strategic Behavior in Voting" by students *Samuel Gilman '21* and *Peter Zhao '21* won the Ward Prize for Best Project in Computer Science. Singh taught Algorithm Design and Analysis (CS 256) in the Spring.

This summer, Singh is working with students *Max Enis '24* and *Jackson Ehrenworth '23* on understanding the preferences and outcomes of algorithms to solve the well-known stable matching problem under practical preference orderings of two-sided markets. Singh is also working with David Lee, *Jackson Bibbens '22*, and McCauley on designing and analyzing learned data structures and algorithms to efficiently search through real-world distributions.

Assistant Professor **Aaron Williams** published two articles on the computational complexity of puzzles and games. Both articles include Williams College students as co-authors, and their contributions began as course projects in the Theory of Computation (CSCI 361) course. The article Block Dude Puzzles are NP-Hard is based on the TI-83+ calculator game Block Dude, and had *Austin Barr '21* and *Calvin Chung '21* as co-authors. The article Motion Planning through Thick and Thin Turnstiles was written with six co-authors, including *Josh Kang '20*. Both articles were accepted at the 33rd Canadian Conference on Computational Geometry.

Williams continued his work in combinatorial generation, with three publications during the year. The article "Hamilton Cycle in the k-Sided Pancake Network" is related to the mathematical problem of pancake flipping, which has applications to genomics. The article "Inside the Binary Reflected Gray Code" shows how a well-known pattern for n-bit binary strings can be adapted into similar patterns for combinatorial objects that can be represented by binary strings. Finally, "A Universal Cycle for Strings with Fixed-Content" generalized a previously known result from permutations to multiset permutations. These three articles were published with Joe Sawada, along with Ben Cameron on the Pancake paper, and Dennis Wong on the Gray Code paper. They will appear this summer at the IWOCA, WADS, and WORDS conferences.

An article in the journal Carbon was also completed in collaboration with his partner Liz Hartung (MCLA) and Jack Graver (Syracuse University). This paper characterizes the conjugated π-systems that can form on capped nanotubes in terms of their chiral indices (n,m).

Post-Graduate Plans of Computer Science Majors

Aponte,Josiel M.	Software Engineer Intern, Salsify, Boston, MA
Baird,Zachary A.	Unknown
Barr,Austin B.	Unknown
Barrett,Erica L.	Unknown
Baumann,Lucien A.	Unknown
Beniers III,Bobby	Unknown
Berger,Jared B.	Associate Software Engineer, Veeva Systems
Button,Elizabeth T.	Software Engineer, MongoDB, New York, NY
Campbell,Kiersten S.	Unknown
Chung,Calvin T.	Software Development Engineer, Amazon/AWS, Seattle WA
Collins,Calvin J.	Unknown
Conroy I,Kaizen C.	Unknown
Davis,Matthew W.	Unknown
Edwards,Teiheim K.	Unknown

Ellert-Beck,Jack	Trading Desk Operations, Jane Street, New York, NY
Feng,Markus Y.	Software Engineer, Jane Street, New York, NY
Gilman,Samuel S.	Software Engineer, PathAI, Boston, MA
Hyatt Jr.,Ethan	Unknown
Johnson,Porter R.	Unknown
Kasab,Solly	Decision Analytics Associate, ZS Associates
Kwon,Justin H.	Unknown
Lange,Jacob V.	Unknown
Lantigua,Edwin J.	Unknown
Lee,David J.	Ph.D. program, Cornell University
Liang,Karmen J.	Software engineer at MongoDB in San Francisco, CA
Liu,Jason	Unknown
Livingston,Raquel E.	Software Engineer, J.P. Morgan Chase & Co., New York, NY
Loose,Gregory S.	Unknown
Mejia,Edwin L.	Unknown
Mercado,Priscilla A.	Unknown
Montano,Octavio	Unknown
Neal,Nevyn	Unknown
Nguyen,Vy T.	M.S. in Computer Science, Carnegie Mellon University, Pittsburg, PA
Romero,Luis D.	Unknown
Salmon,Geoffrey C.	Software Engineer, Google. Mountain View, CA
Schleifman,Matthew A.	Unknown
Stein,Max	Unknown
Street,Noah D.	Data Science Analyst, Citi M&A, NYC
Takigawa,Akihiro	MMath in Applied Mathematics, University of Waterloo, Canada
Thai,Andrew T.	Software Development Engineer, Amazon Web Services, Seattle, WA
Trevithick,Alexander M.	Unknown
Tucher,Julia J.	Software Engineer at ThoughtWorks in San Francisco, CA
Vaccaro,Jamie	Investment Banking Analyst, J.P. Morgan, New York, NY
Varela,Eddy D.	Unknown
Zhang,Xuanzhen	Position at Facebook
Zhao,Peter J.	Software Engineer at Roblox in San Mateo, California

Computer Science Colloquia

Duane Bailey, Williams College
Sigma Xi: “The Software-Hardware Dance: an Evolution”, October 23, 2020

Nicki Washington, Duke University
“Look for the Helpers: Creating and Maintaining a Culture of Advocacy/Activism in Computing+Tech”, March 24, 2021

Kelly Shaw, Williams College
“Smart Home Devices: Why They Don’t Always Work Correctly”, April 1st, 2021

Daniel Seita ’14, University of California, Berkeley
“Robotic Manipulation of Deformable Objects”, April 9, 2021

Joshua Frankel ’02 and Missy Mazzoli
“EMERGENT SYSTEM: A conversation about work at the intersection of art, music, and computer science”, April 14, 2021

Jesse Davis ’02, KU Leuven
“AI-Based Approaches for Analyzing the Performance of Professional Soccer Players”, April 16, 2021

Helen Xu, MIT
“Data Structure Design for Skewed Dynamic Graph Processing”, April 23, 2021

Rediet Abebe, UC Berkeley & Harvard Society of Fellows
“Modeling the Impact of Shocks on Poverty”, May 14, 2021

Off-Campus Computer Science Colloquia

Andrea Danyluk
“Computing Competencies for Undergraduate Data Science Programs” (with Paul Leidig, Andrew McGettrick, Lillian Cassel, Maureen Doyle, Christian Servin, Karl Schmitt, and Andreas Stefik)
SIGCSE 2021, the ACM Symposium on Computer Science Education, March 2021

Kelly Shaw
“Tips for Developing Everyday Research Skills”
RESORC (Research Exposure in Socially Relevant Computing), April 24, 2021

“How to Guide Undergraduate Research”
Women in Computer Architecture (WiCArch) Webinar series, August 6, 2020

Shikha Singh
"The Mechanism Design Approach to Interactive Proofs"
Theory of Computation Seminar, Harvard University, November 9, 2020

"P vs NP"
Microteaching special session, SIGCSE Technical Symposium on Computer Science Education, March 18, 2021

GEOSCIENCES NEWS

A fossilized footprint created by a large bipedal dinosaur during the early Jurassic Period. This is a single footprint from a much larger track of prints that has been installed outside the Bronfman Auditorium in the new Wachenheim Science Center. A larger view of the entire track can be seen on page 16.

In January, the Geosciences Department moved into the newly opened Wachenheim Science Center. It was with much nostalgia that we left Clark Hall, our home since 1908. The move to Wachenheim unites all the department teaching labs, research labs, and offices in one building for the first time. Another momentous change this year was the retirement in June of our petrologist, Bud Wobus, after 55 years on the faculty. The Bud Wobus Rock Garden surrounding the Geosciences wing of Wachenheim contains 12 boulders for use in teaching and was given by a group of alumni in honor of Bud's remarkable career. Bud will continue his research on Colorado geology. The department will search for a new mineralogy and petrology professor this coming year.

Several of our students submitted abstracts to national scientific meetings. *Kate Pippenger '20* and *Devon Parfait '22* each submitted an abstract to the annual Geological Society of America (GSA) meeting in October. The GSA meeting and the December 2020 American Geophysical Union (AGU) meeting were both held virtually this year. Presentations at AGU were given by *Galen Cassidy '21, Dayana Manrique '21,* and *Alex Quizon '21*. Because the meeting was virtual, we were able to provide student memberships to all 7 students taking Climate Change (GEOS 215), and all 16 students in Modern Climate (GEOS 309) so they were able to attend.

Michael Armstrong '20 was the recipient of the Lauren Interess Fellowship award in 2020, but was unable to fulfill his planned trip to Montana due to covid restrictions. Now that covid travel restrictions have eased, Michael is planning on heading to Montana in August where he will explore and record the surficial geology of Montana.

This year's recipient of the Freeman Foote Award, given to the student for the best presentation of their thesis to the Geosciences Department in May, was *Niku Darafshi*

’21. The David Major award, given to the student who makes an invaluable contribution to the Geosciences Department, went to *Hayden Gillooly ’21*. Every year a top senior student in Mineralogy and Petrology is nominated for the American Mineralogist Undergraduate Award given by the Mineralogical Society of America. That honor went to *Aria Mason ’21* this year.

Lecturer **Alex Apotsos** taught Climate Science and Politics (GEOS 221T) during the fall semester. This tutorial was aimed at helping students develop a greater understanding of difficulties associated with crafting climate change legislation. In the spring semester he team-taught Environmental Science (ENVI 102) with Sonya Auer from the Biology Dept. ENVI 102 provides an overview of the interdisciplinary field of environmental science in the context of the interconnected global earth system. Alex also works as a Climate Change Advisor in the Bureau for Africa at the the U.S. Agency for International Development (USAID). In his work for USAID, Alex works on climate services and resilience programs in sub-Saharan Africa.

Research Associate **B. Gudveig Baarli** continued her research on brachiopod lineages spanning the boundary between the Upper Ordovician and Lower Silurian in Norway’s Oslo region based on fieldwork conducted in July 2019 and overcame closure of the basement lab in Clark Hall by setting up a home lab for ongoing work on the diverse atrypid brachiopods from the region that required serial sections revealing internal structures.

Assistant Professor **Alice Bradley** has continued her research in coastal sea ice processes and approaches to observation.

Alice was awarded an NSF grant “Research Networking Activities in Support of Sustained Coordinated Observations of Arctic Change” that works towards coordinating observing efforts across sectors and communities in the Arctic. One of the products so far has been a presentation at AGU fall meeting “Evaluating Global and Regional Observing Frameworks for use in a Coordinated Arctic Observing System.”

Davis Collison ’21 completed her senior thesis on “Observational Network Approaches for the Co-production of Knowledge in Support of Food Sovereignty for Indigenous Alaskan Communities” which evaluated structures of observing organizations working with Arctic communities in the context of a food security framework developed by the Inuit Circumpolar Council. Davis also presented a poster at the 2020 AGU fall meeting “Opportunities for Observations in Support of Indigenous Food Systems in the Coastal Alaskan Walrus Ecosystem”

Galen Cassidy ’22 worked through the summer and the academic year on measuring coastal ice conditions using ground-based marine radar and satellite-based synthetic aperture radar systems. He presented a poster at the 2020 AGU fall meeting, “Filling in the Gap in Coastal Sea Ice Records with Community-Based Observations of Shore and Pack Ice Dynamics”.

Marshall Borrus ’20 finished writing up his thesis work on seismic detection of sea ice ridging and submitted the manuscript to the Seismological Society of America for publication. He presented his follow-on work at AGU as a talk “Seismic Detection of Ridging and Ice Deformation in Coastal Sea Ice near Utqiagvik, Alaska.”

Four students have started new projects in summer 2021: *Kennedy Lange ’24* is working on the detection of ridges in coastal sea ice from satellite laser altimetry, *Annabel Flatland ’24* is investigating the relationship between timing of sea ice freeze-up and melt in first year ice, *Martina Berrutti Bartesaghi ’24* is developing a method to document the relationships between organizations working in Arctic Observing for network analysis, and *Andrew Brito ’22* is investigating the role of river discharge on sea ice melt and freeze-up timing.

Taking advantage of the pandemic and remote participation options, the entire Modern Climate (GEOS 30) class attended the American Geophysical Union Fall Meeting.

Alice developed a new class The Cryosphere (GEOS 410) that explores the role of ice (glaciers, snow, ice sheets, and sea ice) in the global climate system. *Hayden Gillooly ’21* presented her final project research at the 2021 Eastern Snow Conference, “History of Winter Carnival Events in College Archives and Snowfall Observations in Williamstown, MA, 1913-2010.”

Alice continues to serve on the executive committee of the Arctic Observing Summit, where planning is underway for the 2022 meeting in Tromso, Norway. She also serves on the national committee of the Sustaining Arctic Observing Network (US-SAON), and chaired an education session at AGU fall meeting “Teaching Research with Computing.”

The pandemic put a stop to normal research activities in the lab of Associate Professor **Phoebe Cohen** in the summer of 2020. Roman Ruiz ’22 and Mariana Hernandez ’23 were however able to participate in remote research over the summer. They worked on the lab’s ongoing research on the causes and consequences of the Late Devonian mass extinction, and assisted with compiling a database of fossil occurrences from Proterozoic rocks

(2.5-0.54 billion years old) around the world. In the fall, Cohen taught a new introductory course Astrobiology (ASTR 107) in a hybrid format. This class explores how and why life evolved on Earth, and how, why, and where it might evolve elsewhere in the universe. In the spring, Phoebe was on sabbatical and spent her time working on research projects, writing grants, participating in professional development activities, and helping to organize a geoscience-wide anti-racist reading and policy program called URGE: Unlearning Racism in the Geosciences. She was awarded two grants from the National Science Foundation: “Sustaining URGE (Unlearning Racism in Geosciences)”, Collaborator, 2021-2022 and “Collaborative Research: RUI: "CSI Devonian" - testing Late Devonian ocean anoxia proxies across different paleoenvironments", Co-I, 2021-2024 ($75,161). This summer, Phoebe has a full lab consisting of *Roman Ruiz ’22, Mariana Hernandez ’23, Ashlyn Oh ’23,* and *Gwyn Chilcoat ’24*. Roman is working on NSF-funded research to use organic carbon isotopes of single microfossils to shed light on Proterozoic ecosystems, Mariana is working on enigmatic phosphatic fossils from the Paleozoic of Yukon, Canada, and Gwyn and Ashlyn are working on using microfossils to better understand the Late Devonian mass extinction. In addition to her research and teaching, Phoebe continued her work as an inaugural member of the Paleontological Society’s Ethics Committee, as well as her role as Councilor-at-Large for the Paleontological Society’s council. Phoebe was awarded the Geological Society of America’s Geobiology Division Mid-Career Award in the summer of 2021, which will be presented at the fall GSA meeting.

Assistant Professor **José Antonio Constantine**’s research areas include fluvial geomorphology and environmental justice. Ongoing work focuses on the evolution of oxbow lakes, the role of plants in the development of floodplains, and the impacts of urban flooding and pollution on communities of color. He was advisor to two students’ thesis work – *Molly Lohss ’21* (“Indoor Air Pollution and the Legacy of Groundwater Contamination in Tallevst, Florida”) and *Michael Armstrong ’21* (“Controls on the Morphology and Dynamics of Tidal Channels in Plum Island Estuary, Massachusetts”). In addition, he supervised summer research students *Maxine Ng ’22, Marco Vallejos ’20, Molly Lohss ’21,* and *Ruby Bagwyn ’23* during the summer of 2020.

Three research assistants worked on projects in Professor **Mea Cook**'s lab. Maritime Studies senior honors thesis student *Alex Quizon '21* studied how the ocean circulation and nutrient delivery to the sea surface varied over the last 500,000 years in the Bering Sea to test whether there are systematic changes in carbon dioxide leaking from the ocean to atmosphere between ice ages and interglacials. As part of a project funded by the National Science Foundation, *Rheanna Fleming '23* and Geosciences senior honors thesis student *Dayana Manrique '21* studied the chemistry of volcanic ash layers from sediment cores in the Bering Sea and Sanak Island in order to match the layers between land and sea to improve the precision of radiocarbon dating of climate events. Both Alex and Dayana gave oral presentations at the American Geophysical Union fall meeting. Mea Cook also continued her collaboration with Biology faculty member Allison Gill and Environmental Studies Lab Manager Jay Racela to measure a time series of stable isotopes of H and O in rain, ground and stream water in Hopkins Memorial Forest, as well as the stable isotopes of C in inorganic and organic carbon in stream water. Cook is a member of the American Geophysical Union, the National Association of Geoscience Teachers, and the Earth Science Women's Network.

Professor **Rónadh Cox** primarily researches coastal sedimentology and geomorphology, emphasising supratidal coastal boulder deposits and also boulder beaches. Seniors *Aria Mason '21* and *Niku Darafshi '21* completed theses in this area, with Niku focusing on longitudinal analysis of changes in supratidal boulder deposits, and Aria concentrating on developing digital methodologies for robust, statistically valid clast counting techniques that will be applied to the analysis of boulder beaches. In addition, Rónadh continues to work with rising senior *Devon Parfait '22* on measuring land loss rates in southern Louisiana, and documenting the disproportionate effects on Native groups in the region.

Rónadh continues her work with the Geological Society of America, serving in her second year as Chair of the Division of Marine and Coastal Geoscience. *Devon Parfait '22* was recently appointed as the student representative for the Division. She also continues as a member of GSA's Annual Program Committee, for which she will take over the chairmanship this summer.

Now that international travel restrictions related to COVID-19 have been lifted, Rónadh plans field work for this summer in the west of Ireland, where she will supervise data collection for ongoing projects. Incoming thesis student *Hannah Jackson '22* will assist in a new phase of looking at boulder beaches. She will also travel to Gulf Islands National Seashore in Florida, where *Devon Parfait '22* will begin fieldwork with the National Parks Service, mapping bluff erosion in the Naval Live Oaks Area as the basis for his senior thesis.

Professor **Lisa Gilbert** continues several efforts related to sustainability education. This year she advised honors thesis student *Hayden Gillooly '21* on a project comparing the influences of coursework and campus setting on student beliefs, motivations, and behaviors related to sustainability. Gilbert has also been working on the leadership team for a new project of the American Chemical Society's Green Chemistry Institute; she is helping manage a team of chemistry professors to develop curricular modules for introductory General and Organic Chemistry courses that will improve students' sustainability and systems thinking skills. In addition, Gilbert's NSF grant "Earth Education for Sustainable Societies" offered over 70 mini-grants to earth educators engaged in activities to support sustainability education and related DEI initiatives and she and her co-investigators published an article in the publication EOS to share the community-written vision statement and a call for participation from more geoscience researchers in sustainability education.

Emeritus Professor **Markes Johnson** signed a contract with the University of Arizona Press for his third book on the geology of Mexico's Baja California peninsula and adjacent Gulf of California in September 2020. His newest contribution comes under the title Baja California's Coastal Landscapes Revealed, and underwent final editing in May 2021 with a release date scheduled for Fall 2021. The book highlights mapping performed during the 2016 excursion to the Gulf of California with Williams students during the spring semester, as well as later excursions with a focus on storm beds of Pliocene, Pleistocene, and Holocene age.

During the spring semester 2021, Markes offered an adult-education course via ZOOM with the Osher Lifelong Learning Institute (OLLI). This included a dozen lectures on the topic of "Islands in Deep Time" based on his studies of paleoislands around the world ranging in age from the Cambrian to the Pleistocene. Although the covid-19 pandemic eliminated the possibility for fieldwork during all of 2020 and much of 2021, data previously accumulated on island deposits in the Gulf of California as well as other parts of the world including the Canary Islands and coastal Norway allowed for ongoing research and publication.

Professor **Paul Karabinos** and collaborator Jim Crowley (Boise State University) continued their research on the rifting history of Rodinia during the Late Precambrian. They published an abstract for the online National Geological Society of America Meeting in October 2020 based on this work.

Karabinos and collaborators Maureen Long (Yale), Vadim Levin (Rutgers), and Laura Webb (University of Vermont) continued their integrated geology and geophysics project to image the lithosphere from the surface to the asthenosphere in New England. They have installed six seismometers (one in the basement of Clark Hall) between Petersburg, New York, and Greenfield, Massachusetts, and an additional six instruments in Vermont and New Hampshire. The lines will be expanded in eastern Massachusetts and northern New England. The project is designed to search for structures preserved in the lithosphere from the mountain building history of the New England Appalachians, look for overprinting features that may have developed during the rifting of Pangea and formation of the Atlantic, and assess the importance of ongoing mantle dynamics. *Ethan Lopes '20*, Karabinos, and Long published their work on seismic anisotropy in northern Connecticut as an abstract for the Northeastern Section Meeting of the Geological Society of America in Hartford, Connecticut, in March, 2021, and as a paper in *Geochemistry, Geophysics, Geosystems*. Yantao Luo (Yale), Long, Karabinos, and Yvette Kuiper (Colorado School of Mines) presented their work on receiver function analysis of seismic data from Connecticut at the Northeastern Section Meeting of the Geological Society of America.

Karabinos organized a theme session for the 2020 National Geological Society of America Meeting with Chong Ma, Paul Mueller, David Foster, and Cees van Staal entitled: "From Rodinia to Pangea: Evolution of the Appalachian-Caledonian Orogen."

Karabinos organized the speaker series for the Geosciences Department during the 2020-2021 academic year.

Professor **Bud Wobus** retired at the end of the 2020-21 school year after 55 years on the Williams faculty. Until last year he had taught every geology major since he arrived in 1966; one slipped through in 2020, and a couple more will this year. Many of his students, including 40+ thesis advisees, took all of his regularly offered courses, often beginning with his Geology of the National Parks Winter Study and continuing through An Unfinished Planet (GEOS 102), Mineralogy (GEOS 202), and Igneous & Metamorphic Petrology (GEOS 303), followed by two semesters of thesis. Dozens of majors accompanied him in summers for field work in the Southern Rockies or along the Maine coast, funded by the USGS, the Keck Geology Consortium, and the Geosciences Department. With a career-long focus on undergraduate research as the cornerstone of a science major, he co-founded the Geology section of the Council on Undergraduate Research and, in 1969, the NSF-sponsored WAMSIP-Geology Consortium ("Williams-Amherst-Mt Holyoke-Smith Interinstitutional Project") for collaborative field-oriented research among students and faculty of those four colleges. Taking this idea one giant step forward, he and colleague Bill Fox submitted the enabling proposal to the W.M. Keck Foundation in 1986 that established the Keck Geology Consortium, which grew to 18 colleges coast-to-coast and which subsidized the research of nearly 100 Williams geology students over 30 years. For his work in attracting students to geology, he received the Neil Miner Award from the National Association of Geosciences Teachers in 2016.

Several of his former students organized a special session in his honor at the annual meeting of the Geological Society of America in Portland, OR, in the Fall of 2021 where he and two recent students (*Erikka Olson '19* and *Christian Lockwood '20*) made presentations. He will continue his study and writing about Colorado geology from his long-time office in Clark Hall, the former home of the Geology Department, and looks forward to welcoming geosciences alumni and their families to his house during reunion weekends.

Top: This plaque attached to a large piece of pink precambrian granite from the Colorado front range, dedicates the area near the Southwest entry of the Wachenheim Science Center as the Bud Wobus Rock Garden.

Bottom: Additional views of the garden area.

Post-Graduate Plans of Geosciences Majors

Nalamakuikapo Ahs-ing	Unknown
Michael Armstrong	Boston College Mater's Program in Earth and Environmental Sciences
Niku Darafshi	Undecided
Hayden Gillooly	Unknown
Austin Huang	Undecided
Cleveland Lavalais	Unknown
Molly Lohss	Environmental consulting Industrial Economic, Inc, Cambridge, MA
Dayana Manrique	Service year with AmeriCorps NCCC-FEMA Corps July 2021-July 2022
Aria Mason	Business Analyst at McKinsey & Company, Boston
Annalee Tai	Unknown
Julia Ward	Unknown

An exact replica of a Velociraptor fossil keeps watch over Hoxsey Street from the window of the Geosciences student lounge in the Wachenheim Science Center.

Geosciences Colloquia

Alice Bradley
"Cold, Dark and Violent: Measuring Sea Ice in a Changing Climate"
2020 Summer Faculty Lecture Series, organized byWilliams College Alumni Relations

Dr. Laura Ruhl, Univ. of Arkansas Little Rock, 4th Annual Environmental Justice Lecture
"Clean Coal? The Environmental and health Impacts of Burning Coal"

Dr. Laura Webb, University of Vermont, Class of 60's Scholars
"New Insights into Old Problems in the Green Mountains from Integrated 40Ar/30Ar Geochronology and Microstructural Analyses"

Dr. Dwight Bradley, U.S. Geological Survey, Sperry Lecture
"Detrital Zircons and the Tempo of Plate Tectonics Through Earth History"

Dr. Rachel Beane '93, Bowdoin College, Class of 60's Scholars
The Taupo Volcanic Zone: New Zealand's Supervolcano"

Dr. Will Amidon, Middlebury College, Class of 60's Scholars
How Did Recent Tectonic Events Shape the Landscape of New England?"

Dr. Kaustubh Thirumalai, University of Arizona
"An El Niño Mode in the Indian Ocean?"

Geosciences Student Colloquia

Michael Armstrong '21
Biophysical Controls of Plum Island Estuary Tidal Channel Dynamics

Niku Darafshi '21
2019-2000 Atlantic Storm Season and its Impacts on Boulder Movement along Western Ireland

Molly Lohss '21
Conducting an Indoor Air Quality Analysis for Tallevast, Florida: A Majority Black Community Facing TCE Contamination

Dayana Manrique '21
Tephrochronology in the Aleutian Islands and Bering Sea: Assessing Tephra Correlations in Marine and Terrestrial Sediment Cores

Aria Mason '21
Developing Digital Clast-Counting Methodology for Analysis of Boulder Beaches

Alex Quizon '21
What Drives CO2 Changes over Glacial-Interglacial Cycles? Controls on Nutrient Utilization and the Biological Pump in the Subarctic Pacific

Off-Campus Geosciences Colloquia

Alice Bradley

“Mind the Gap: Moving from Graduate to Early Career in Observational Science – Arctic Observing Systems Collaboration Sub-Team”

Arctic Research Policy Committee, March 2021

José Constantine

“Case Studies from the Social Geography of Environmental Risk”

University of Nevada, Reno, 2020

University of Montana, 2021

University of Minnesota, 2021

Illinois State University, 2021

“Futures for Geomorphology in Environmental Justice”

Geological Society of America Annual Meeting, Montreal, 2020

Rónadh Cox

“Combining Field Geoscience and Math to Understand Coastal Erosion"

University College Dublin Earth Institute Connecting Collaborators workshop, March 4, 2021

"Megagravel in Coastal Boulder Deposits Records Storm Wave Power"

Future Earth Coasts Fellows Colloquium, May 3, 2021

AAAS Annual Meeting, May 11, 2021

"Coastal Boulders and Mgagravel Record Extreme Overland Flow Velocities During Storm Wave Inundation: Relevance for Long-term Coastal Management Strategies"

Coastal Cultural Heritage and Climate Change Conference, May 12, 2021

“Coastal Megagravel: How Big Boulders on Rocky Coasts are Changing the Way We Think about Storm Waves"

Conference of Irish Geographers, May 18, 2021

Lisa Gilbert

“Preparing for an Academic Career in Geoscience”

Earth Educators Rendezvous (online), 13-15 July 2020

“Chemistry Education for a Sustainable Future: Green Chemistry Module Developmen,” American Chemical Society webinar, 5 August 2020

“Teaching Systems Thinking in Oceanography”

Geological Society of America Annual Meeting (online), 22 October 2020

“Green & Sustainable Chemistry Module Development Initiative: Developer Teams & Systems Thinking”

American Chemical Society webinar, 11 November 2020

“Building Inclusive Teaching Practices into Green and Sustainable Chemistry Curricular Materials”

American Chemical Society webinar, 21 January 2021

“Mitigating Risks from Natural Hazards: A Systems Approach to Science, Policy, and Uncertainty” Michigan State University, ESP 600 guest lecture (online), 6 April 2021

“Discipline-based Education Research in the Geosciences”

North Carolina State University, MEA 507 panel (online), 4 May 2021

“Green & Sustainable Chemistry Module Development Initiative: Cohort 2 Developer Teams & Systems Thinking”

American Chemical Society webinar, 1 June 2021

“Green & Sustainable Chemistry Module Development Initiative: Cohort 2 Developer Goal-Setting”

American Chemical Society webinar, 10 June 2021

Math & Stats News

At the end of the challenging Academic Year 2020-2021, marked by the unprecedented disruption caused by the COVID-19 pandemic, we are very proud of the 72 seniors who graduated with a major in Mathematics and the 14 who graduated with a major in Statistics. The Department of Mathematics and Statistics has finally moved into their wonderful new home in the Wachenheim Science Center.

We are thrilled to have hired a new colleague, Annie Tang, who joined us in July 2021 as a Visiting Lecturer in Statistics. Annie is a PhD candidate in Statistics at North Carolina State University doing research in Bayesian and Bayesian-like methods for high-dimensional/complex data. Four of our colleagues left Williams this year: Josh Carlson has started as an Assistant Professor of Mathematics at Drake University, Eva Goedhart is now a Visiting Assistant Professor of Mathematics at Franklin & Marshall College, Haydee Lindo is an Assistant Professor of Mathematics at Harvey Mudd College, while John Wiltshire-Gordon is an engineer at a software company in the Boston area. We will miss them and we wish them all the best.

Among the faculty accomplishments throughout the year, Pamela Harris was selected as one of the Inaugural class of Karen Uhlenbeck EDGE Fellows and also won the 2021 Marion and Jasper Whiting Foundation Fellowship and Steve Miller won the 2021 Churchill Adviser Award given by the Winston Churchill Foundation. Professors Colin Adams, Julie Blackwood (spring), Thomas Garrity, Eva Goedhart (fall), Haydee Lindo, Cesar Silva, and Elizabeth Upton (spring) were on leave for 2020-2021. Professors Xizhen Cai, Leo Goldmakher, Allison Pacelli (spring), Anna Plantinga, and Laurie Tupper will be on leave during 2021-2022.

In February 2021, 11 Williams students took (remotely) the notoriously difficult national Putnam exam. Williams' top scorers were Zachary Stein-Perlman, Yuan Qiu, Maxim Enis, Max Everett, Alexander Simons, and Peter Hollander. Thanks to all who participated and to all who cheered them on.

Finally, we thank the members of our student advisory board, SMASAB, who organized many virtual Math/Stat events during the Academic Year: Kimberly Hadaway (president), Novera Rahman Momo (vice-president), Rain Condie (secretary/treasurer), Preetul Sen (SIAM representative), AMS Representative: Saisha Gooboodun (AMS Representative), Jihong Lee (ASA Representative), Liza Jacoby (AWM Representative), Tony Zou (Stat Majors Representative), and Fiona Campbell (Sophomore Representative).

We are very proud of the accomplishments of our majors. The prizes awarded by the Department at the end of the Academic Year were:

Award Name	**Recipient(s)**
Rosenberg prize for outstanding senior	Emil Graf '21, Robin Huang '21
Goldberg award for outstanding colloquium	Christopher Thomas '21 (math), Samuel Wolf '21 (stat)
Wyskiel award for teaching	Spencer Brooks '21
Morgan prize in applied math	Julia Tucher '21
Kozelka award for outstanding student in statistics:	Faris Gulamali '21
Beaver prize for service to the department and math/stat community	Kimberly Hadaway '21
Benedict prize for outstanding sophomore	First Prize: Jianing Ren, Sarah Shi Second Prize: Vera Cao, Annie Lu
Witte problem solving prize	Zachary Stein-Perlman '21
Colloquium attendance prize	Daniel Park '21
National Science Foundation Graduate Research Fellowships in the mathematical sciences	Emil Graf '21, Robin Huang '21
Gates Cambridge scholarship	Nick Goldrosen '20
Class of 1945 Florence Chandler Memorial Fellowship	Jonathan Deng '21

Finally, the Math and Stats department hosted or co-hosted several speakers fot the Class of 60 Scholars program:

Invited Speakers for the Class of 1960 Scholars Program
Rebecca Nugent, Carnegie Mellon University
Ravi Vakil, Stanford University
Ronald L. Wasserstein, American Statistical Association

Professor **Colin Adams** was on leave for the 2020-21 academic year. In summer 2020, he had a knot theory research group as a part of the SMALL Undergraduate Research Program with six students. They are finishing up three papers that resulted. Adams spent the year working on a variety of research projects. In particular, together with three students, he wrote a paper that determines the non-edge-to-edge tilings of the sphere by regular polygons. He also wrote a textbook entitled *The Tiling Book: An Introduction to the Mathematical Theory of Tiling*. In 2021, the *Encyclopedia of Knot Theory* was published, for which he was an editor and for which he contributed four articles. He continues as a humor columnist for the *Mathematical Intelligencer* and a managing editor for the *Journal of Knot Theory and its Ramifications*.

Over the past year, Associate Professor **Julie Blackwood** has continued several ongoing projects in mathematical ecology. In particular, she continues to work on modeling the dynamics of infectious diseases in both humans and animals, exploring questions related to identifying the drivers of spatiotemporal patterns of disease and implications for control. Diseases that Blackwood study include dengue virus and white nose syndrome in North American little brown bat populations. Her work over the past year also focused on developing optimal management strategies for populations when decisions are made by multiple levels of government. Applications of this work include fisheries and disease management.

Blackwood advised two thesis students: *Thomas Kirby '21* and *Nehemiah Wilson '21*. Tommy's work focused on managing tick populations and Nehemiah focused on evaluating management strategies for COVID-19 in prison populations.

In the past year, Assistant Professor **Xizhen Cai** continued to do research in the areas of her research interests. She has worked on projects relating to variance estimation in cross validation, variable selection in high-dimensional settings for semiparametric and mediation models, applications and generalizations of statistical learning methods. During the year, she published two research articles, one is on a novel pedagogical approach for teaching multivariate statistical method and the other is on the variable selection methods and theory for high-dimensional semiparametric models. She was invited to give a guest lecture at Wellesley College in December 2020, presented her work at Symposium on Data Science and Statistics and Joint Statistical Conferences in the summer of 2020. She worked with summer research student *Jianing Ren '23* on applications of classification methods and is finishing the collaborative book of English text rhetorical analysis with collaborators outside Williams. In the year, she developed and taught a new course Applied Statistical Modeling (STAT 302), and also taught multivariate statistics (STAT 355) and Statistical Learning and Data Mining (STAT 442).

Professor **Dick De Veaux** continued his work in data science, writing textbooks and gave some invited talks and workshops. However, given the pandemic, most of these were given virtually. Dick continued his term as Vice President of the American Statistical Association (2019-21). He served as associate chair of the department from July 1, 2020 to June 30, 2021 and resumed his role as chair on July 1.

Professor **Tom Garrity** has spent the year on sabbatical. Due to the pandemic, he of course could not travel and thus spent the year doing math in Williamstown, continuing his research in number theory. His papers, "Functional analysis behind a Family of Multidimensional Continued Fractions: Part I" and "Functional analysis behind a Family of Multidimensional Continued Fractions: Part II," both written with *Ilya Amburg '14*, have been accepted in *Publicationes Mathematicae*. The second edition of his book *All the Math You Missed: But Need to Know for Graduate School* (Cambridge University Press) with four new chapters, will appear this coming summer. He has also done a fair amount of work on shoring up mathematical infrastructure, meaning mostly reviewing and refereeing various papers and book proposals.

Associate Professor **Pamela E. Harris** taught Multivariable Calculus (MATH 150) and Undergraduate Research Topics in Graph Theory (MATH 392T).

Harris was a recipient of the 2020 Inaugural Class of The Karen EDGE Fellowship Program, which was established with a generous gift from Karen Uhlenbeck on the occasion of her 2019 Abel Prize. The Fellowships are designed to support and enhance the research programs and collaborations of mid-career mathematicians who are members of an underrepresented minority group.

Professor Harris is highly committed to fostering the success of underrepresented scientists and to improving diversity and retention rates among women and minorities in the mathematical sciences. This year, she had a grant renewed to support the website www.lathisms.org whose mission is to provide an accessible platform that features prominently the extent of the research and mentoring contributions of Latinxs and Hispanics in different areas of the Mathematical Sciences. Moreover, a highlight of 2020-21 academic year is the completion of the book *Asked and Answered: Dialogues On Advocating For Students of Color in Mathematics*, coauthored with Dr. Aris Winger.

In addition, she published five research articles and had many others accepted for publication Professor Harris presented 18 invited research lectures.

Professor **Stuart Johnson** remains active in dynamical systems, furthering his work in optimal control and applied dynamics. He continues his work in spatial coupled dynamics and evolutionary games.

Professor **Bernhard Klingenberg** taught a new course on Data Visualization and Reproducible Research in the fall semester, with some, but not all emphasis on visualizing various COVID statistics. On the research side, he worked with biologists on a statistical analysis of sex differences in approach- and mating calls for frogs. Their paper appeared in the *Journal of Experimental Biology.* Klingenberg also wrote a paper that addresses a wrong application of the Mantel-Haenzel method in analyzing stratified data, in the context of infometrics and the evaluation of scientific output and continued as associate editor for the journal *Statistical Modeling*. Finally, after nearly two years of work, Klingenberg published the 5th edition of the statistics textbook *Statistics, the art and science of learning from data.* Jointly with the book, he published several new or updated web-apps to the website artofstat.com/web-apps, helping students around the world understand and carry out basic statistics.

Professor **Susan Loepp** spent most of summer 2020 preparing to teach her classes in a hybrid format for the 2020-21 academic year. She learned how to make prerecorded videos, how to have students turn in all work online, and how to record her live lectures. Given all of the challenges of the 2020-21 academic year, she thought that her classes went relatively well, and considers the year, in many ways, to be a valuable learning experience.

In summer 2019, Loepp advised the Commutative Algebra research group as part of the Math/Stat department's SMALL program. The group included the two Williams students *Erica Barrett '21* and *Emil Graf '21*. Two papers based on the groups' original results were submitted to refereed research journals, and one of the papers recently appeared in the *Rocky Mountain Journal of Mathematics*. The other paper has been accepted in a volume of the American Mathematical Society's *Contemporary Mathematics*. During the academic year 2019-20, she advised the senior honors thesis of *Teresa Yu '20*. Two manuscripts resulted from this collaboration. One recently appeared in the *Journal of Algebra* and the other has been submitted for consideration for publication in a refereed research journal.

Loepp continues her work as an elected member of the Council of the American Mathematical Society. She attended the Council meeting in January at the (virtual) Joint Mathematics Meetings. She also participated in the April Council meeting (virtually) and several other informal Council meetings. In 2020-21, she gave two (virtual) talks on her research at AMS conferences. Loepp is serving in her third 5-year term as an associate editor for the *Mathematical Monthly*, and, over the past year, she served on several committees for the American Mathematical Society

Professor **Steven Miller** continued his work in number theory and probability, writing 20+ papers and giving 30+ talks with students (including co-organizing the 19th International jointly with students). He was the Director of the Williams SMALL summer math research program, where he advised 13 students. He took a leadership role in helping Math Research Experiences for Undergraduates pivot to a virtual summer (started those conversations in February 2020).

Miller, with three other colleagues, created the Polymath Jr REU program to help students across the world who lost research opportunities. We accepted over 300 students in 12 projects in 2020, and will have over 400 in 18 projects in 2021. Anyone who had taken a proof class and had a letter of recommendation was admitted. The program was a tremendous success. We ran two groups of 20+ students and had other undergraduates (including from Williams) serve as TAs and learn how to guide research. This year's program was funded by a new NSF grant, where Miller is one of the PIs.

Miller continues to serve on the Mount Greylock Regional School Committee, where he uses mathematics to solve problems for the district. He and his students successfully consulted on a variety of projects, including a multi-million dollar MLB lawsuit and numerous local start-ups. He has been active in numerous education initiatives, from continuing education classes for teachers to writing computational modules for schools to running a shared, on-line Introduction to Data Science class through LACOL. His courses have been freely available on his webpage for years, and he volunteered extensively to assist others in moving online. He continues to serve on several editorial boards, especially Pi Mu Epsilon (Problem Editor) and the *Journal of Number Theory* (one of four Managing Editors), and is a Senator-at-Large for Phi Beta Kappa. Talks, papers, and all class lectures and many course materials are available freely online at https://web.williams.edu/Mathematics/sjmiller/public_html/ .

Professor **Frank Morgan** after four itinerant years since retirement, fulfilled a life-long dream by moving into a little condo on the Boardwalk in Ocean City, New Jersey.

During his fifth year at Williams College, Assistant Professor **Ralph Morrison** continued his research in tropical geometry and chip-firing games on graphs. He advised a group of six students (*Marino Echavarria, Max Everett '21, Robin Huang '21, Liza Jacoby '22, Raluca Vlad,* and *Ben Weber '21*) in the Tropical and Algebraic Geometry group of the remote 2020 SMALL REU; and seven students (*Lisa Cenek, Lizzie Ferguson '22, Eyobel Gebre '22, Cassandra Marcussen, Jason Meintjes '22, Liz Ostermeyer '22.5,* and *Shefali Ramakrishna*) for the 2021 iteration of the SMALL REU, for which he was also the Assistant Director. He also advised the senior theses of *Max Everett '21, Robin Huang '21,* and *Ben Weber '21*. He gave many remote talks, participated remotely in ICERM's Spring 2021 semester on Combinatorial Algebraic Geometry, and co-organized the remote Discrete Math Days conference at Williams in April 2021. He taught three sections of Multivariable Calculus (MATH 151) in Fall 2020, which included a trip to WCMA's Object Lab; and he taught Tropical Geometry (MATH 474) in Spring 2021. He received an NSF Grant to support his work with students on chip-firing games on graphs.

During the past year, Assistant Professor **Shaoyang Ning** taught Elementary Statistics and Data Analysis (STAT 101) and designed a new course, Applied Machine Learning (STAT 315).

He continued on his research on the study and design of statistical methods for integrative data analysis, in particular, to address the challenges of increasing complexity and connectivity arising from "Big Data". He has been primarily working on projects utilizing Google search data for high-resolution, local level flu activity prediction as well as using digital data to track economic index such as Unemployment Initial Claims. During the academic year 2020-21, he published two papers, one on state-level flu tracking with Internet data in *Scientific Reports* and another on unemployment prediction in the *Journal of American Statistical Association*.

Ning co-organized and participated in the 2020 NextGen Data Science Day (DSD) Conference by New England Statistical Society (NESS) and also served as Associate Editor for NESS' new journal *The New England Journal of Statistics in Data Science* (NEJSDS). He also organized and chaired an Organized Invited Session on "Advances in statistical methods and application with digital data" at the 13th International Conference of the ERCIM WG on Computational and Methodological Statistics (CMStatistics 2020).

Professor *Allison Pacelli* continued her teaching and research in algebraic number theory and can't wait to be back in person this fall. She continues to teach her summer camp (PZMC) for mathematically gifted high school students as well.

Assistant Professor **Anna Plantinga** continued her research in statistical methods for analysis of human microbiome data, particularly in the presence of modern study design features such as longitudinal studies and multiple high-dimensional data sources. She also works collaboratively with biologists and clinicians investigating the role of the microbiome in diseases such as irritable bowel syndrome (IBS) and bacterial vaginosis. During the year she published a collaborative paper investigating the role of changes in the microbiome in effectiveness of an IBS treatment; a textbook chapter outlining major approaches to microbiome beta diversity analysis; and a paper describing an R package for microbiome beta diversity based in part on summer research completed by *Nehemiah Wilson '21*.

In the past year she presented at the Joint Statistical Meetings and the Eastern North American Region of the International Biometric Society's annual meeting (ENAR), both of which were held virtually. Thesis student *Daniel Park '21* carried out the research presented at ENAR. To encourage young statisticians and data scientists in the field, she helped organize the New England Statistical Society NextGen Committee's annual Data Science Day conference. She taught Longitudinal Data Analysis (STAT 372), Statistics & Data Analysis (STAT 201), and a new course, Biostatistics and Epidemiology (STAT 335), in hybrid and virtual formats.

Since fall 2019 and until August 2021, Professor **Cesar Silva** has been serving as a program director in the Division of Mathematical Sciences of the National Science Foundation. In May of 2021, his student *Alex Trevithick '21* completed his thesis "On the Representation of Low-Dimensional Signals with Periodic Activation Functions". Silva published a paper, submitted two papers for publication and has some others in progress.

Professor **Mihai Stoiciu** served as the Chair of the Department of Mathematics and Statistics during the Academic Year 2020-21, and, starting from July 1 2021, is serving as the Associate Chair for Mathematics. He taught Foundations in Quantitative Skills (MATH 102) during the Fall Semester and Probability (STAT 341) during the Spring Semester. He also taught the interdisciplinary course Mathematics and Poetry: From Order to Chaos, together with American Studies Professor Cassandra Cleghorn during Summer Science 2020. Stoiciu continued as a member of the Summer Science Program faculty during the Summer of 2021.

Stoiciu was invited to give a presentation of his research at an AMS Special Session at the 2021 MAS/MAA Joint Mathematics Meeting and was an invited panelist in a virtual MAA panel about undergraduate research in analysis and differential equations. During the academic year, Stoiciu served as a member of the Liberal Arts Collaborative for Digital Innovation (LACOL) Faculty Advisory Council and represented Williams College at the 2021 LACOL Workshop, hosted virtually by Hamilton College.

Assistant Professor **Daniel Turek** returned from his sabbatical in France and taught his classes fully remotely this year. His course offerings included Bayesian Statistics as a 400-level capstone course in the Statistics major, with the addition of an independent research project and presentation.

Assistant Professor **Elizabeth Upton** taught Statistics and Data Analysis (STAT 201) in the fall semester and was on leave in the spring. Professor Upton continued her research in statistical methods for network-indexed data. She also continues to work collaboratively with epidemiologists on social network analysis for public health research. During the year, Upton coauthored two published papers and presented her research at the INSNA Sunbelt conference. She also served as a reviewer for two publications: *Sankhya A*. and *Statistics Education Research Journal*. Upton is currently working with two summer research students, *Daniel Lee ‘23* and *Alan Sun ’23*.

The SMALL 2021 group on Chip-Firing Games, in the brand new Frank Morgan Library (*Jason Meintjes '22, Liz Ostermeyer '22.5, Lizzie Ferguson '22, Lisa Cenek, Shefali Ramakrishna, Eyobel Gebre '22,* and *Cassandra Marcussen*)."

The math library in the Bronfman Science Center which was beloved by the Math/Stats departments has been largely recreated in the new Wachenheim Science Center. The space is a bright and spacious area for students to gather and study. The area was named in honor of Frank Morgan, Professor of Mathematics, Emeritus.

Post-Graduate Plans of Mathematics and Statistics Majors

Austin Barr	Unknown
Abigail Barrett	Unknown
Erica Barrett	Unknown
Justin Berman	Attending graduate school in Physics at the University of Michigan
Felix Biwott	Unknown
Brianna Bourne	Unknown
Rodrigo Bravo	Unknown
Spencer Brooks	Teaching high school math
Daulet Cheryazdanov	Unknown
Ejay Cho	Working as an Associate at Marakon
William Conyers	Unknown
Matthew Davis	Unknown
Maddie Dekko	Unknown
Benjamin Delgado	Working as an RA at the Atlanta Fed
Beyond Deng	Working as a Research Assistant for the Economic Studies Program at the Brookings Institute in DC
Lydia Duan	Working at a non-profit support foundation for an Asian women's uni-versity next year in Cambridge, MA
Ella Dunn	Working for a private equity finance firm in Boston
Cameron Edgar	Pursuing a Ph.D. in Mathematics at Boston University
Jack Ellert-Beck	Trading Desk Operations Specialist at Jane Street in New York
Jesus Estrada	Unknown
Max Everett	Pursuing a Ph.D. in Mathematics in Algebraic Geometry at CUNY
Markus Feng	Working as a Software Engineer at Jane Street
Michael Gao	Unknown
Saisha Goboodun	Unknown
Emil Graf	Pursuing a Ph.D. in Mathematics at Cornell University
Michael Greenberg	Unknown
Faris Gulamali	Unknown
Kimberly Hadaway	Attending a Ph.D. program in Mathematics
Brendan Hall	Pursuing a Ph.D. in Biophysics at UC San Francisco
Peter Hollander	Pursuing a Ph.D. in Mathematics at UC Irvine in the fall of 2022. In the meantime, working as a Software Developer at Epic Systems in Madison, WI.
Robin Huang	Pursuing a Ph.D. in Mathematics at UC Berkeley
Paul Hwang	Unknown
Ethan Hyatt	Unknown
Samuel Jocus I	Unknown
Porter Johnson	Unknown
Adam Jones	Unknown
Rishad Karim	Unknown
Evan Kauffmann	Unknown

Hashim Khan	Unknown
Thomas Kirby	Working in the Williamstown area
Benjamin Kitchen	Pursuing a Ph.D. in Mathematics at the University of Colorado, Boulder
Alexander Kitt	Working in Credit Suisse’s Mergers and Acquisitions group in New York
Justin Kwon	Working as a Software Engineer at Google in Seattle, WA.
Patrick Lang	Unknown
Jacob Lange	Unknown
Samantha Lazar	Unknown
David Lee	Unknown
Victoria Liu	Unknown
Gregory Loose	Internship with Northrop Grumman Corporation over the summer, then attending Carnegie Mellon University with the intent to earn a Master's degree in computer science
Cory Lund	Unknown
Ben Maron	Working as a Firefighter/EMT in the fall
Carolina Martinez	Unknown
Edwin Mejia	Unknown
Eli Miller	Unknown
Novera Rahman Momo	Unknown
Brynn Moynihan	Working at City Year for a year then going into Consulting at Bain
Vy Nguyen	Unknown
Alexander Paolozzi	Working in Investment Banking in New York
Daniel Park	Working as a Technology Analyst at Roivant Sciences
Eshaan Patel	Unknown
Gabriel Patenotte	Pursuing a Ph.D. in Physics at Harvard
John Petrucci	Working as a Rotational Development Program Analyst at Jane Street in New York City
Aayushi Pramanik	Working in Investment Banking at Barclays in New York City
Daniel Queen	Working in consulting at Semler Brossy Consulting Group
Noah Reich	Unknown
Daniel Renwick	Unknown
Maria Rodriguez Hertz	Summer research project on senior thesis
Tyler Scott	Working at GE Healthcare and joining their Financial Management Pro-gram
Alex Simons	Unknown
Kasey Stern	Associate Consultant at Trinity Partners
Akihiro Takigawa	Pursuing a Master’s Degree (MMath) in Applied Mathematics at the University of Waterloo
Andrew Thai	Unknown
Christopher Thomas	Working as an Associate in Teaching at Norfolk Academy in Norfolk, VA.
Alexander Trevithick	Pursuing a Ph.D. in Computer Science at UC San Diego
Julia Tucher	Working as a Software Engineer at ThoughtWorks in San Francisco
Sarah Tully	Working in a Rotational Program at Fidelity’s Capital Markets group
Nicholas VanBelle	Working in Investment Banking at Morgan Stanley
Xiwen Wang	Unknown

Benjamin Weber	Software Developer at Epic Systems
Katrina Wheelan	Working at University of Chicago's Urban Labs as a Project Associate in their Energy and Environment Lab
Nehemiah Wilson	Unknown
Anna Wise	Working in finance at Amazon
Samuel Wolf	Working as the Communications, Policy, and Research Associate to the Global Executive Director at J-PAL, an economic development research group based out of the MIT Economics Department
Bryan Woolley	Attending UMass, Amherst in fall 2022 for a two-year dual master pro-gram, working toward an MBA and a Masters of Sports Management
Tarun Yadav	Unknown
Xuanzhen Zhang	Unknown
Peter Zhao	Unknown
Tony Zou	Unknown

Mathematics and Statistics Student Colloquia

Austin Barr
"Voting Theory and Weighted Systems"

Abigail Barrett
"Gambler's Ruin: Solution and Applications"

Erica Barrett
"Lattice-Based Cryptography and the NTRU Cryptosystem"

Justin Berman
"There is No Elementary Antiderivative for e^{-x^2}"

Felix Biwott
"Mathematical Modeling of Soccer Dynamics"

Brianna Bourne
"Modeling Cardiac Pacemakers with a Modified van der Pol Oscillator"

Rodrigo Bravo
"The Mathematics Behind Bitcoin: Encryption, Probability, and Blockchain Technology"

Spencer Brooks
"Applying Combinatorial Game Theory in Chess Endgames"

Daulet Cheryazdanov
"The Implementation of Game Theory for Optimal Decision Making on The Price is Right"

Ejay Cho
"An Application of Latent Dirichlet Allocation (LDA) on Covid19-related Tweets"

William Conyers
"Is Happiness Contagious?: An Answer Using Longitudinal Social Network Analysis"

Matthew Davis
"Modelling Synchrony in Biological Systems"

Maddie Dekko
"Voting Systems: The Impossibility of a Perfect Storm"

Benjamin Delgado
"Optimal Control for Electoral Behavior"

Jonathan Deng
"Can We Agree to Disagree?"

Lydia Duan
"Bertrand's Paradox and the Principle of Indifference"

Ella Dunn
"Partial-Linear Modeling Using a Difference-Based Method: Potential Applications to Economics"

Cameron Edgar
"Determining Optimal Outfield Shifting Strategies for Major League Baseball Teams"

Jack Ellert-Beck
"Proving Quadratic Reciprocity With Cyclotomic Fields"

Jesús Estrada
"Modelling Unorganized Segregation With Modern Dynamical Systems Theory"

Max Everett
"Multiplicity-Free Gonality on Graphs"

Markus Feng
"Knight's Tour on Rectangular Chess Boards"

Michael Gao
"Rate-Induced Tipping: Applications in Ecological Models"

Saisha Goboodun
"Using Persistent Homology to Analyze Development and Geographic Global Trends"

Emil Graf
"Structures on the Space of Multiplicative Functions"

Faris Gulamali
"E3G – Echo State Networks Applied to Electroencephalography Data: Interpretable Hyperdimensional Computing on Spatiotemporal Data"

Michael Greenberg
"Evolution of Infectious Disease Modelling: Agent-Based Modelling in MERS-CoV Superspreading Dynamics in the Republic of Korea"

Kimberly Hadaway
"On Combinatorial Problems Related to Generalized Parking Functions"

Brendan Hall
"A Simple Model of Protein Folding Kinetics"

Clara Hathorne
"Polynomial Resultants and Applications"

Peter Hollander
"(t,r) Broadcast Domination on Directed Graphs"

Robin Huang
"The Tropical Three Conics Theorem"

Paul Hwang
"Hosmer Lemeshow Test for Bernoulli Results"

Ethan Hyatt
"Iterative Prisoner's Dilemma and the Folk Theorem"

Porter Johnson
"Coalition Formation as it Relates to Friends in Classes"

Rishad Karim
"The Mathematics Behind Tetris: Enumerating, Tiling and More With Polyominoes!"

Evan Kauffmann
"Mathematics of the Rubik's Cube"

Hashim Khan
"The Mathematics of Card Tricks"

Thomas Kirby
"Potential for Control of Deer Ticks Using the Sterile Insect Technique"

Benjamin Kitchen
"Positive Semidefinite Throttling on Directed Graphs"

Justin Kwon
"Markov Chains and Applications"

Alexander Kitt
"The Nash Bargaining Solution: Finding Game Theory Equilibrium in Bargaining Problems"

Patrick Lang
"Generalizing the Proof of Nash Equilibrium to an nxn Game"

Jacob Lange
"The Height of Irrationality"

Samantha Lazar
"The Utilization of Survival Analysis to More Fully Investigate Sleep Patterns"

David J. Lee
"Evaluating How Smartphone Contact Tracing Technology Can Reduce the Spread of Infectious Disease"

Gregory Loose
"Conway's Angel Problem"

Victoria Liu
"Wine Logistics and Supply Chain Management"

Cory Lund
"Latin Squares: Partial Solutions and Applications"

Ben Maron
"Properties of a Two Dimensional Model of RNA Folding"

Carolina Martinez
"The Skew Throttling Number of a Graph"

Edwin Mejia
"Primitive Roots and Gauss' Proof"

Eli Miller
"Using Height Functions to Determine Tileability"

Brynn Moynihan
"Exploring Classroom Learning Through Social Network Analysis"

Vy Nguyen
"Dynamic Egocentric Models for Citation Networks"

Alexander Paolozzi
"There Isn't Enough Room for Infinity Utility in Only Two Envelopes"

Daniel Park
"New Approaches to Volatility Analysis of the Human Gut Microbiome and Associations With Health Outcomes"

Eshaan Patel
"Applications of the Laplace Functional for Point Processes"

Gabriel Patenotte
"The Plancherel Theorem for Fourier Transforms"

John Petrucci
"Hopping Forcing on Graphs"

Aayushi Pramanik
"The Efficacy of Non-Pharmaceutical Interventions on COVID-19 Transmission"

Daniel Queen
"Election Forecasting Using Dynamical Systems"

Novera Rahman Momo
"The Möbius Strip and Its Applications in Architecture"

Noah Reich
"Differential Games"

Daniel Renwick
"When Should Coaches Pull Their Goalie in Ice Hockey"

Maria Rodriguez Hertz
"Weight q-multiplicities for Representations of Lie Algebra C3"

Tyler Scott
"Rubin's Causal Model and the Mexican Drug War"

Alex Simons
"Composition of TG-Hyperbolic Virtual Knots"

Kasey Stern
"Tipping Through Rapid Rewiring in an Epidemic Model"

Akihiro Takigawa
"An Investigation of Virus Dynamics on Starlike Graphs"

Andrew Thai
"The Road Coloring Problem on Directed Graphs"

Christopher Thomas
"Stay Safe in Every Way: Let's Play Poker 6,000 Feet Apart"

Alexander Trevithick
"On the Representation of Low-Dimensional Signals With Periodic Activation Functions"

Julia Tucher
"Modeling Teacher-Student Race Match in California Public Schools"

Sarah Tully
"Damage Throttling in a Game of Cops and Robbers"

Nicholas VanBelle
"The Marchenko-Pastur Distribution for Random Correlation Matrices and an Application to Financial Market Portfolios"

Xiwen Wang
"Tiling the Sphere with Regular Polygons"

Benjamin Weber
"On Gonality-Related Graph Parameters"

Katrina Wheelan
"Investigating the Role of School Homogeneity on Student Outcome Disparities in Chicago Public Elementary Schools"

Nehemiah Wilson
"COVID and the American Prison Industrial Complex: The Mathematical and Humanitarian Advantages of Decarceration"

Anna Wise
"Product Throttling"

Samuel Wolf
"Bayesian Partitioning Approaches to Record Linkage Uncertainty"

Bryan Wooley
"When Linearity Fails: Using Nonparametric Measures to Assess Monotonicity in Variable Relationships"

Tarun Yadav
"A Sensitive Approach to Spatiotemporal Patterning in Urban Violent Crime"

Xuanzhen Zhang
"Poker and Bluffing"

Peter Zhao
"The Gonality of Random Graphs"

Tony Zou
"Informed Bayesian Inference for the A/B Test"

Mathematics and Statistics Colloquia

Rebecca Nugent, Carnegie Mellon University
"Demystifying Data Science"

Ravi Vakil, Stanford University
"The Mathematics of Doodling"

Ronald L. Wasserstein, American Statistical Association
"Living with the Improbability Principle"

Off-Campus Mathematics and Statistics Colloquia

Colin Adams

"Lower Bounds on Volumes of Hyperbolic 3-Manifolds"
Penn State AMS sectional meeting (Virtual), October 5, 2020

"Knotted Proteins, Quandles and Bondles"
Chattanooga AMS sectional Meeting (Virtual), October 11, 2020

"Riot at the Calc Exam Discussion"
Wakefield Middle School (Virtual), November 23, 2021

"Humorous Math Theater"
Joint Mathematics Meetings (Virtual), January 9, 2021

"Lower Bounds on Volumes of Hyperbolic 3-Manifolds"
Topology Seminar, University of California Davis (Virtual), January 19, 2021

"On Another Plane"
Mathematical Intelligencer Webinar for Marjorie Senechal (Virtual), February 27, 2021

"Polylinear and Knotted Sculptures"
Talk with Anton Bakker, Museum of Mathematics (Virtual), March 31, 2021

"Multi-Crossing Number and Petal Number for Classical and Virtual Knots"
Knots and Representation Theory Seminar, Moscow State University (Virtual), April 19, 2021

"Why Knot?"
Fitchburg State University High School Math Contest Keynote Talk (Virtual), April 30, 2021

"The Future of Undergraduate Textbooks" Panel
Western Sectional Meetings, America Mathematical Society (Virtual), May 2, 2021

"Multi-crossing Number and Petal Number for Knots"
KAIST Conference on Knot Theory, Korea (Virtual), May 25, 2021

Julie Blackwood

"Uncovering the Drivers of Spatial Synchrony of Periodical Cicadas in the U.S."
Virginia Tech

Sixth International Conference on Mathematical Modeling and Analysis of Populations in Biological Systems
Society for Mathematical Biology Annual Meeting

Xizhen Cai

"Mediation Models and Its Extension to Time-Varying Data"
Invited Guest Lecture, Wellesley College, December 2020

"An Efficient Variance Estimator for Cross-Validation Under Partition-Sampling"
The 2021 Symposium on Data Science & Statistics Virtual Conference, June 2021

Richard De Veaux
"The Seven Deadly Sins of Data Science"
Pontificia Universidad Javeriana, Bogota, Columbia (Virtual), September 2020
Midwest Math & Stats Student Conference, Kansas City, MO, (Virtual), April 2021

Workshops and Short Courses:
"How to Negotiate for your First Job"
NISS Workshop for Beginning Faculty (Virtual), March 2021

"Modern Regression"
West African Young Statisticians Conference, Lagos, Nigeria (Virtual), June 2021

Thomas Garrity
"Dynamical Systems Stemming from a Family of Multi-Dimensional Continued Fraction Algorithms"
Dynamical Systems Seminar, University of Pisa, Italy, January 2020

Pamela Harris
Plenary Talks:
"Recent Results on Kostant's Partition Function"
Women in Combinatorics and Representation Theory, UC Riverside, May 2021

"Partitions and Juggling: A Story of Unifying Parts and Seeking Balance in Mathematics"
Launchpoint Mathematics Conference, April 2021

"Partitions and Juggling: A Story of Unifying Parts and Seeking Balance in Mathematics"
Hispanic Graduate Student Association Talks, Florida State University, April 2021

"Parking Functions: Choose Your Own Adventure"
Advancing Student Participation in Research Experiences (ASPiRE) Conference, Florida Gulf Coast University, March 2021

"Partitions and Juggling: A Story of Unifying Parts and Seeking Balance in Mathematics"
Math For All in New Orleans, March 2021

"Parking Functions: Choose Your Own Adventure"
Convocation Speaker, NC Governor's School, June 2021
Hobart and William Smith Colleges, REU talk, June 2021
NYC Combinatorics Seminar, May 2021
Iowa State Mathematics Colloquium, February 2021
CMS Winter Meeting, Algebraic Combinatorixx Session, December 2020

"Kostant's Partition Function and Magic Multiplex Juggling Sequences"
Math SWAGGER Colloquium, March 2021
Women in Combinatorics Colloquium, February 2021
Gustavus Adolphus College, Mathematics Colloquium, February 2021
Purdue University, Mathematics Colloquium, February 2021
Carleton College, Mathematics Colloquium, January 2021
OURFA^2M^2 Conference, December 2020
MSU Combinatorics Colloquium, December 2020
St. Olaf College, Graph Theory Talk, November 2020

"On the (t,r) Broadcast Domination Number of Graphs"
Trinity University, Math Colloquium, October 2020

"Invisible Lattice Points"
Cibercoloquio Latinoamericano de Matemáticas, Virtual talk in Spanish, September 2020

Bernhard Klingenberg

“ArtofStat at K-12 Chat”
Online presentation hosted by the ASA’s K-12 statistical ambassador, 2020

"Seeing is Believing”
Electronic Conference on Teaching Statistics (Online), 2020

Susan Loepp

“Completions of Uncountable Local Rings with Countable Spectra”
AMS Special Session on Commutative Algebra, Joint Mathematics Meetings (Virtual), January, 2021

“Completions of Countable Excellent Local Domains”
AMS Special Session on Homological Commutative Algebra, Fall Southeastern Sectional Meeting (Virtual), October, 2020

Steven Miller

“Cookie Monster Meets the Fibonacci Numbers. Mmmmmm -- Theorems!”
Williams and Texas State REUs, July 8, 2020

“Gaps Of Summands of The Zeckendorf Lattice”
Presented by SMALL 2019* and Eureka 2018, 19th International Fibonacci Conference, July 21, 2020

“Completeness of Positive Linear Recurrence Sequences”
Presented by SMALL 2020* 19th International Fibonacci Conference, July 21, 2020

“Generalizing Zeckendorf's Theorem to Non-Constant Coefficient Recurrences”
Presented by Eureka 2020 and Polymath REU*, 19th International Fibonacci Conference, July 22, 2020

“Asymptotic Analysis For Lattice Walks Derived From Zeckendorf Decompositions”
Presented by CMU students and Eureka 2019, 19th International Fibonacci Conference, July 23, 2020

“Generalizing Zeckendorf's Theorem to Homogeneous Linear Recurrences”
Presented by Thomas Martinez, 19th International Fibonacci Conference, July 23, 2020

“Zeckendorf Games” (Kevin Ke, Carl Ye, Vashisth Tiwari), Northeast REU Math Conference, July 2020
“Prime Walks to Infinity in Z[√2]”
(Daniel Sarnecki and Bencheng Li), Northeast Math REU Conference, July 2020

“Completeness of Positive Linear Recurrence Sequences”
(Fernando Trejos, John Lentfer, John Haviland, Ela Boldyriew, Phuc Lam), Northeast REU Math Conference, July 2020

“All I Need to Know About Probability I Learned from Darth Vader and James Bond”
Hampshire College Institute for Summer Studies in Mathematics, August 3, 2020

“The German Tank Problem: Math/Stats At War”
PROMYS, August 7, 2020

“Constructions of Generalized MSTD Sets in Higher Dimensions”
(Elena Kim, John Lentfer, John Haviland, Phuc Lam, Fernando Trejos Suarez), Young Mathematicians Conference, August 2020

“More Sums Than Differences Sets in Finite Non-Abelian Groups”
(John Haviland, John Lentfer, Elena Kim, Phuc Lam, Fernando Trejos Suarez), Young Mathematicians Conference, August 2020

“Juggling Coefficients in Complete Recurrent Sequences”
(Ela Boldyriew, Phuc Lam, John Lentfer), Young Mathematicians Conference, August 2020

"Analytic Approaches to Completeness of Generalized Fibonacci Sequences"
(Fernando Trejos, John Lentfer, John Haviland, Ela Boldyriew, Phuc Lam), Young Mathematicians Conference, August 2020

"Bounding the Zeroing Algorithm: A Tool for Investigating Linear Recurrence Relations"
(Jack Murphy*), Young Mathematicians Conference, August 2020

"Split limiting Behavior of Random Matrices with Prescribed Discrete Spectra"
(Yuxin Lin, Jiahui Yu, Fangu Chen), Young Mathematicians Conference, August 2020

"Tinkering with Lattices: A New Take on the Erdos Distance Problem"
(Elena Kim, Fernando Trejos Suarez, Jason Zhao), Young Mathematicians Conference, August 2020

"Determining Optimal Test Functions for 2-level Densities"
(Ela Boldyriew, Fangu Chen, Jason Zhao), Young Mathematicians Conference, August 2020

"Extending Virus Dynamics to k-level Star-Like Graphs"
(Akihiro Takigawa '21*, Jack Murphy*, Rodrigo Bravo '21), Young Mathematicians Conference, August 2020

"Prime Walks to Infinity in Z[√2]"
(Daniel Sarnecki and Bencheng Li), Young Mathematicians Conference, August 2020

"Zeckendorf Games"
(Kevin Ke, Carl Ye, Vashisth Tiwari), Young Mathematicians Conference, August 2020

"Why I Love Monovariants: From Zombies to Conway's Soldiers via the Golden Mean"
Math Club, University of Michigan, September 10, 2020

"Why The IRS Cares About the Riemann Zeta Function and Number Theory (and why you should too!)"
UConn Math Club, September 16, 2020

"Prime Walk to Infinity in Z[√2]"
(Daniel Sarnecki, Bencheng Li), PAJAMAS, September 2020

"Walking to Infinity Along Some Number Theory Sequences" (given by Tudor-Dimitrie Popescu), PAJAMAS, September 2020

"Tinkering with Lattices: A New Take on the Erdos Distance Problem"
(Elena Kim, Fernando Trejos Suarez), Quebec-Maine Number Theory Conference, September 26, 2020

"Determining optimal test functions for 2-level densities"
(Jason Zhao) Quebec-Maine Number Theory Conference, September 26, 2020

"The German Tank Problem: Math/Stats At War"
Penn State, October 29, 2020

"From the Manhattan Project to Elliptic Curves"
Michigan Math Club, January 21, 2021.

"How Low Can We Go? Understanding Zeros of L-Functions Near The Central Point"
New York Number Theory Seminar, February 18, 2021

"Analyzing Virus Dynamics on k-level Starlike Graphs"
(with Akihiro Takigawa), Spring 2021 AMS Eastern Sectional Meeting: Special Session on Applications and Asymptotic Properties of Discrete Dynamical Systems: A Session in Honor of the Retirement of Orlando Merino.

"CUR-Goldwater Faculty Mentor Award"
May 12, 2021

Frank Morgan, Williams College

"Geodesic Nets and Soap Films"
SUMRY, Yale University, June 17, 2020

"Honeycombs and Densities, Including Multiple Bubbles in Gauss Space"
Moscow (Online), September 14 - 19, 2020

"Double Bubbles and Densities"
University of South Florida (Virtual), September 25, 2020
University of Western Australia (Virtual), November 4, 2020

"Optimal Tiles"
Southern Georgia Math Conference and MAA Georgia State Luncheon (Virtual), April 3, 2020

"Optimal Pentagonal Tiles"
Celebration of Mind (Gathering for Gardner) (Virtual), May 21, 2020

Ralph Morrison

"The Importance of Being Wrong in Mathematics"
Mentor Project Luncheon Seminar (Remote), March 2021

"Tropicalize ALL the Things"
Washington and Lee University, Pi Mu Epsilon Induction Speaker, March 2021

"Higher-distance Commuting Varieties"
University of Kentucky, Mathematics Colloquium, March 2021

"Chip-firing Games and Graph Gonality"
Santa Clara University, Mathematics Colloquium, April 2021

"Tropically Planar Graphs: Counting and Constraints"
Goethe-Universität Frankfurt, DIGO Seminar, June 2021

Shaoyang Ning

"Using Google Search Data for Localized Flu Tracking"
Wearable and Implantable Technology Group, Johns Hopkins University (Virtual), January 28, 2021

Anna Plantinga

"Distance-Based Analysis for Longitudinal Multi-Omic Data"
Joint Statistical Meetings (Remote), August 2020

"Microbiome Volatility and Longitudinal Microbiome Analysis"
Eastern North American Region of the International Biometric Society, Co-authored with Daniel Park '21, (Remote), March 2021

Mihai Stoiciu

"Convergent Point Processes and Their Rates of Convergence"
AMS Special Session on Analysis and Differential Equations at Undergraduate Institutions, AMS/MAA Joint Mathematics Meetings (Virtual), January 2021

"Starting and Sustaining Undergraduate Research in Analysis and Differential Equations"
MAA Virtual Panel, June 2021

Daniel Turek

"Leading a 2-day Bayesian Statistics Workshop"
Home Laboratory Montpellier France

"Leading a 1-day Bayesian Statistics Workshop"
Institute National de la Recherche Agronomique (INRA), Saint-Pée-sur-Nivelle, France

“Visiting Collaborators”
CIRAD Agricultural Research for Development laboratory, Montferrier-sur-Lez, France

“Leading a 1-day Bayesian Statistics Workshop”
Norwegian University of Science and Technology, Trondheim, Norway.
This was sponsored by the Fulbright Inter-Country Lecturing Program

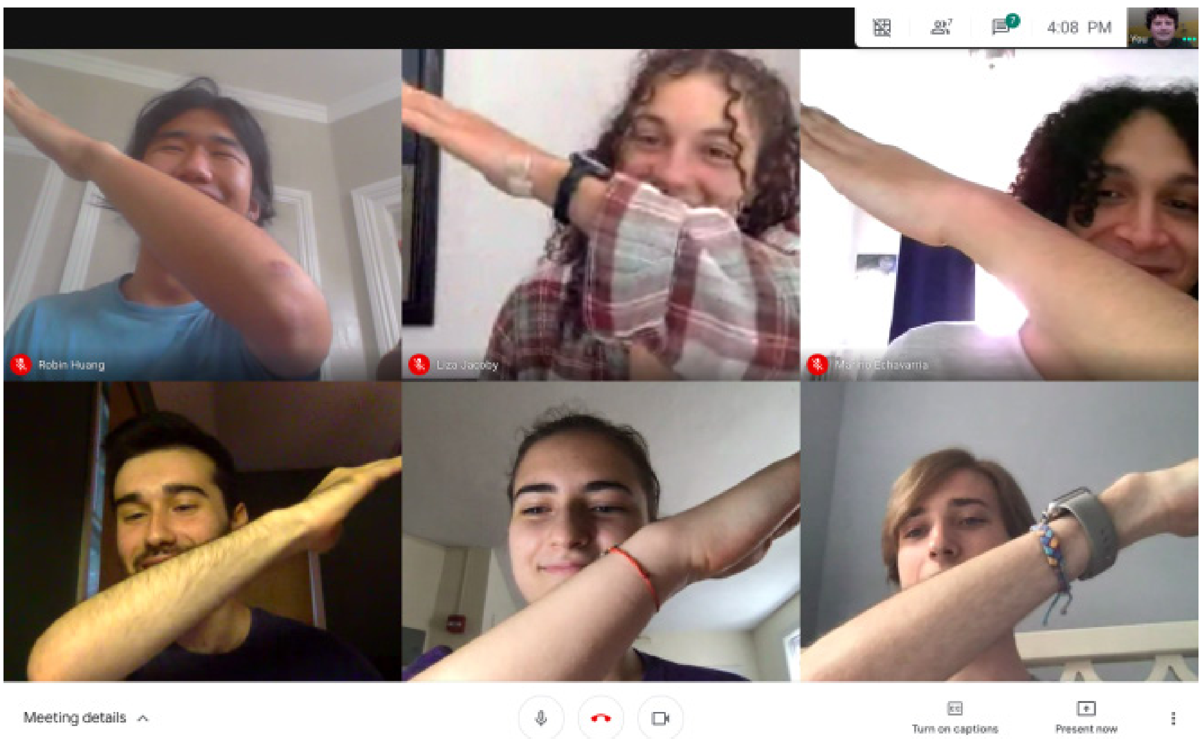
“Articipating in the Project Wildmap Wildlife Management Program,”
Norwegian University of Life Sciences, in Ås, Norway

“Invited Talk”
Statistical Sciences Group of the University of Exeter, in Exeter, UK
This was sponsored by the Fulbright Inter-Country Lecturing Program

Elizabeth Upton

“Modeling Occurrences of Residential Burglary via Bayesian Network Regularized”
Sunbelt: International Network for Social Network Analysis, Virtual Conference, 2020

“Regression Methods for Network Indexed Data: Modeling Occurrences of Burglary and Identifying Correlates of Injection Drug Use”
Amherst College, 2020



The SMALL 2020 remote group on Tropical Geometry, doing their best impression of a triangulation Students (*Robin Huang '21, Liza Jacoby '22, Marino Echavarria, Ben Weber '21, Raluca Vlad,* and *Max Everett '21*).

Physics News

The Department of Physics has experienced significant change in the past few years, with the departure of Sarah Bolton in 2016 (to President of the College of Wooster) and the retirements of Jeff Strait and Bill Wootters in 2017 and Kevin Jones in 2020. With these changes, we have been graced by new faces and new directions for the department, most recently with the arrival of Henrik Ronellenfitsch, a theoretical physicist coming from MIT. We are also grateful for the joint appointments of Kevin Flaherty and Anne Jaskot from Astronomy. We are also pleased to have Brough Morris continuing as our Instruction Support Specialist, working alongside Kevin Forkey, our longtime master technician of classroom demos, laboratory equipment, and other magical marvels. Supporting us all is the dedicated work of Michele Rech.

Research with students is a central activity of physics department faculty. In the summer of 2020, 32 students did research with physics faculty. Numerous other students did research during the academic year, some as part of a senior honors thesis. The research activities of our faculty and students focus on diverse topics in both experimental physics (atomic, hard, and soft condensed matter) and theoretical physics (biophysics, particle physics, and quantum information).

On the teaching front, we continued to offer a variety of elective courses in addition to our core curriculum. This upcoming year these electives will include a non-majors course on Energy, Science, and Technology, an upper-level tutorial in electrodynamics, special courses on gravity, solid state physics, computational biology, as well as an interdisciplinary course bridging philosophy and physics.

The Physics department continues to participate in the 1960 Scholars program. This year 14 physics students were named as scholars:

Class of 1960 Scholars in Physics	
Ilana Albert	Gabriel Patonette
Justin Berman	Nicholas Patino
Nico Coloma-Cook	Patrick Postec
Declan Daly	Joshua Reynolds
Brendan Hall	Paige Robichaud
Hyeongjin Kim	Matthew Roychowdhury
Duncan McCarthy	Declan Smith

Professor **Daniel Aalberts** was honored to become the Kennedy Richardson '71 Professor of Physics. He taught Introduction to Computer Science (CSCI 134) and Statistical Physics (PHYS 302). Aalberts presented the Spring 2020 Sigma Xi Lecture, speaking about mRNA vaccine technology. In Summer 2020, he worked with *Qiyuan Hu '20* and *Brendan Hall '21* measuring the statistics of ribosome pausing. In Summer 2021, *Brendan Hall '21* is modeling biases in ribosome profiling experiments and *Isaac Wilkins '22* is modeling how changing the ribosome initiation site alters protein production and mRNA decay.

During 2020-21 Assistant Professor **Charlie Doret** taught Quantum Physics (PHYS 301) in a hybrid format to approximately twenty students. This course is the college's most laboratory-intensive physics course, and by pairing in-person and remote students into two-person lab groups the course was able to maintain much of the traditional laboratory component for all students. During the spring Doret welcomed a group of 23 students to Foundations of Modern Physics (PHYS 142), where a mix of in-person and remote work and a large number of chalk-on-the-sidewalk problem solving sessions allowed for the preservation of small group problem solving, traditional laboratory work, and numerical work in Mathematica.

Outside of the classroom, Doret's research focuses on work with trapped atomic ions. Such ions can be exquisitely controlled using lasers and electric fields, allowing them to be used as tools to emulate the behavior of more complicated quantum systems of interest. One particular focus for Doret's lab is to try to better understand thermal conductivity at the nanoscale, relevant both to quantum information processing with trapped ions and for understanding power dissipation in microelectronic devices. However, the same exceptional control over atomic systems can also be used to make precise measurements of atomic structure to test models for physics beyond the Standard model.

While traditional laboratory work was made complicated by the pandemic, the Doret group continued to make progress on a variety of fronts. During Summer 2020 incoming thesis students *Paige Robichaud `21* and *Matthew Roychowdhury `21* and research student *Aidan Ryan `22* worked during Summer 2020 on equipment design and simulation projects which could be accomplished remotely. Paige developed sets of voltages to be used to control ions in a new-to-the-Doret-group ion trap from Sandia National Lab, while Matthew and Aidan work towards new designs for an `blade'-style ion trap and an ultrastable laser, respectively. Paige & Matthew's thesis work was featured in a virtual poster presentation at the APS DAMOP conference in June 2021. Doret gave an invited talk on searches for Dark Matter based on precision isotope shift measurements; he also enjoyed catching up with other Williams atomic physicists, including Professor Tiku Majumder and about fifteen alumni ranging from the classes 1993 through 2021.

During Summer 2021, Aidan is continuing his work in the laboratory as he starts a senior thesis, where he has been joined by *Timmy Chang `23, Renée DePencier Piñero `23,* and *Bless Bah Awazi `24*. Aidan and Timmy will be taking over responsibilities for trapping ions in the new trap assembled by Paige, while Renée and Bless will be building a new laser at 423 nm, frequency stabilized to a Rb vapor cell, for use as a stable frequency reference and for future use in trapping Sr+.

Assistant Professor **Graham Giovanetti** taught Introduction to Mechanics (PHYS 131) in Fall 2020 and Vibrations, Waves, and Optics (PHYS 202) in Spring 2021. Both courses were taught in a hybrid format to simultaneously accommodate students learning remotely and in-person. Conducting lectures and laboratories in this format proved to be a challenging but interesting exercise, and some of the ideas and technologies adopted this year will find their way into future, fully in-person versions of the courses.

Giovanetti continued his research using low-background, underground detectors to search for rare physics events. In summer 2020, *Save Koontaweepunya '21, Duncan McCarthy '21, Fil Niewinski '22,* and *Declan Smith '21* worked remotely to develop a framework for performing Monte Carlo simulations to design and optimize a new liquid argon detector for light dark matter. Duncan and Declan followed up on this work during the academic year by constructing a liquid argon test-bed at Williams for developing novel detector technologies, ultimately completing senior theses on the project. Four new students joined Professor Giovanetti this summer. *Tim Saffold '22* will complete the simulation study started last summer alongside a team of collaborators from the DarkSide collaboration, and *Will Zhang '22, Ryan Gross '23,* and *Rafay Kazmi '23* will employ the liquid-argon system to study argon electroluminescence and several ideas for improving photodetection in liquid argon detectors. Professor Giovanetti was a co-author on several papers, including a new result limiting the allowable half-life for excited state decays of ^{76}Ge to longer than 10^{23} years.

Assistant Professor **Kate Jensen** spent the 2020-21 academic year on sabbatical, adapting her materials physics lab's research on understanding the mechanics of soft materials and interfaces to both remote and hybrid formats. Sixteen Williams students contributed to research efforts in Jensen's laboratory in the past year, working to understand the physics underlying soft adhesion and surface mechanics (*Joey Headley '21, Adam Dionne '22, Emily Kuwaye '23, Eshaan Patel '21*), analyzing deformation mechanisms in colloidal glasses (*Aidan Duncan '23*), developing new theory and simulation tools (*Sophia Millay '21, Ryan Watson '22, Brianna Binder '22*), cultivating plants that use energy from water to reproduce (*James Fortin '22*), and developing new research directions investigating fluid surface instabilities (*Harrison Toll '22, Charlotte Jones '22*). The lab also added new experimental capabilities with an interferometric microscope (*Nick Patiño '21, Nico Coloma-Cook '21, Ethan Cooper '23*), expanded surface tension measurement apparatus (*Rose Tchuenkam '23*), and an adhesion tester (*Sonya Dutton '24*), all student-built.

Nick Patiño '21, an Allison Davis Research Fellow, completed his senior thesis entitled *Linnik Interference Microscopy for Measuring High-Speed Dynamic Mechanics*. *Caroline Tally '21.5* continued her senior thesis research on the physics of leaking flows, including how a leak can stop itself, a project now supported by an Undergraduate New Investigator research grant from the American Chemical Society's Petroleum Research Fund. Caroline also received the first Edward N. Perry 1968 and Cynthia W. Wood Summer Science Research Fellowship to support this work in Summer 2021. *Rose Tchuenkam '23* recently joined this project as well as the lab's newest Allison Davis Research Fellow.

Professor Jensen continues to have very active collaborations both at Williams and beyond. She was recently awarded a major NSF research grant to study "Hydropowered Plants: How Primitive Land Plants Reproduce by Harnessing Mechanical Energy from Water," on which Williams Biology Professor Joan Edwards is a key collaborator. The Jensen Lab also recently teamed up with new Williams Physics Professor Henrik Ronellenfitsch and his students to start a joint Journal Club reading and discussing research articles. Beyond the Purple Valley, Jensen and several of her students have continued to collaborate with Tufts theoretical physicist Tim Atherton as well as colleagues at Harvard's School of Engineering and Applied Sciences. Professor Jensen has also continued to collaborate closely and publish with colleagues at ETH Zürich, where she will spend Fall 2021 as a Visiting Professor in the Department of Materials.

The Jensen Lab attended several virtual conferences this year, including "bringing" students to the American Physical Society (APS) Division of Fluid Dynamics meeting, the APS March Meeting (5 student talks), and the June New England Complex Fluids Workshop (3 student talks). The students also competed in "Complex Fluids Trivia" at the workshop, and proudly won third place, defeating numerous graduate students, postdocs, and professors.

Assistant professor **Catherine Kealhofer**'s research focuses on the development of tools to generate, manipulate, and characterize ultrafast electron pulses. Ultrafast electron pulses are extraordinarily short pulses of electrons that could extend electron microscopy techniques to study processes that happen very fast—for example, to make a "movie" of how atoms in a crystal rearrange during a phase transition.

In 2020, the summer research program was entirely remote, due to the pandemic. Four students (*Ilana Albert '21, Declan Daly '21, Nelly Lin-Schweitzer '21,* and *Joshua Reynolds '21*) worked full time on remote research projects, focusing on simulations in support of the experiment design and construction. Ilana, Declan and Josh continued working in the lab in the fall as honors thesis students (and were thrilled to be able to do in-person experimental work). Nelly is an English and Physics double-major and wrote a thesis in the English department.

Ilana spent the summer simulating laser-induced heating of samples in an ultrafast electron diffraction experiment. In the fall, she worked on preparing samples and characterizing them with optical and atomic force microscopy. Nelly simulated electrostatic deflectors, and Declan and Josh simulated ultrafast pulse propagation in fiber using python, which has been a useful tool for understanding their results once they returned to the lab. For his senior thesis, Josh built two femtosecond fiber oscillators and began construction of a ytterbium fiber chirped-pulse amplifier, with assistance from William Renninger's group at the Institute of Optics at the University of Rochester. This laser system will be used to generate ultrafast electron pulses and is the core of the experimental apparatus. Declan Daly, built a frequency-resolved optical gating (FROG) apparatus, which is used to characterize ultrafast laser pulses.

Nelly has the John A. Lowe III Special Collections Fellowship for 2020-21, and Ilana, Josh, and Declan are all starting graduate programs this coming fall: Ilana is entering the PhD program in Physics at Northeastern University, Josh is starting a PhD in Applied Physics at Stanford University, and Declan is starting a PhD in Physics at the University of Maryland. Former thesis students *Emily Stump '18* and *Iona Binnie '19* were both awarded NSF Graduate Research Fellowships this year. They are currently pursuing PhD's in Physics at Cornell and the University of Colorado, Boulder, respectively.

Incoming thesis student *Benny Weng '22* is taking over both Josh and Declan's projects, using the FROG as a tool in the completion of the ytterbium fiber amplifier. Current summer students *Katie Brockmeyer '24* and *Da-Yeon Koh '24* have taken on a diverse array of projects in the lab, including building electronics related to the fiber amplifier and etching nickel field-emission tips to test as electron sources.

Prof. Kealhofer's research is currently funded by the Research Corporation for Science Advancement, through a Cottrell Scholar Award. As part of this award, Kealhofer piloted changes to the Seminar in Modern Physics course (Physics 151) last fall, introducing students to reading original physics papers as part of the course. In the last year, she has refereed a paper for *Physical Review Applied*, given a colloquium at Dartmouth, and attended the Cottrell Scholars Conferences in July 2020 and 2021.

McElfresh Professor of Physics ***Kevin Jones '77*** completed his final semester of teaching at Williams and, as of July 2021, became the McElfresh Professor of Physics Emeritus. In the fall of 2020 he cotaught a tutorial course, Classical Mechanics (PHYS 411T) with Henrik Ronellenfitsch and introductory labs with Graham Giovanetti. Due to the ongoing COVID pandemic the teaching was all virtual, but the students adapted remarkably well to the situation and made good progress despite the unusual circumstances.

In the spring Jones was on leave and worked as a program director at the National Science Foundation, helping to run the Atomic, Molecular and Optical Experimental Physics program. He is continuing this position post-retirement. His main role is to find expert reviewers for proposals, select and led review panels and then make recommendations on awards and declines. He has also been involved with initiatives designed to broaden participation in physics, helping draft a "Dear Colleague Letter" describing funding opportunities to support graduate and undergraduate researchers from groups underrepresented in physics. Recently he lead a panel evaluating a new grant opportunity aimed at helping beginning researchers start research programs which broaden participation in physics.

Jones continues to keep a hand in research working with long time colleague Dr. Paul Lett at the Joint Quantum Institute on the University of Maryland campus.

During an unprecedented year for all of us at Williams, Professor **Tiku Majumder** taught a 'hybrid' version of Introductory Mechanics and Waves (PHYS 141) in the fall of 2020 which included all-virtual labs! In summer 2020, he supervised two 'remote' internships for thesis students *Gabriel Patenotte '21* and *Patrick Postec '21*. While this was particularly challenging given the very hands-on nature of our laser/atomic physics research, we came up with a lot of simulation/design/theory work to help prepare the students for return to the lab in fall 2020. The work in the Majumder lab continues to be generously funded by the National Science Foundation which has supported the purchase of equipment, the hiring of students, and, importantly, the hiring of a series of postdocs in the group, the most recent of whom, John Lacy (PhD 2019, U Sussex, UK), has been with the group for the past year and a half. He has been a wonderful partner in all of the work in the lab, supervising and mentoring students, and generally pursuing a variety of both hands-on and more theoretical projects to support and move forward multiple experiments.

Professor Majumder also continued his work, now extending over the past decade, as Science Center Director at Williams, overseeing budgets and our summer internship program, supporting student/faculty research generally, as well as working with science chairs and others at the College on science-wide matters. Most notably, this year marked the opening of the second of our two new science building (Wachenheim science center), marking the end of a seven-year process of planning, design, and construction, and the completion of the largest capital project in the College's history. Majumder also chaired the College's elected 'Faculty Steering Committee' during the busy, complicated spring of 2021.

Gabriel Patenotte '21 completed a thesis during this very challenging year by demonstrating the feasibility of a new spectroscopic measurement of lead atomic transitions, making use of a laser system that he designed, built, and optimized over the past two years. He also did substantial theoretical work to model and interpret the experimental results which he obtained. Gabriel will be starting in the Physics Ph.D. program at Harvard this fall, making him the fourth thesis student from the Majumder lab to attend Harvard to continue atomic and molecular physics research in the past six years. *Patrick Postec '21* completed a thesis which outlined the development and testing of a new experimental system to confine large lead samples in a 'heat-pipe oven' to allow the detection of a very, very weak (and never before measured) atomic transition in that element. Patrick will be serving in the Americorps program for 2021-22, and then plans to apply to mechanical engineering Ph.D. programs to focus on sustainable, alternative energy development.

Also part of the team during this past academic year was *Charlotte Jones '22* who worked on a variety of optics, electronics, and mechanical design projects for the lab. All of the research projects in the lab are aimed at making highly precise spectroscopic measurements of the atomic properties of key heavy elements to support and test state-of-the-art theoretical modeling of the quantum mechanics of these complex systems. We were thrilled to welcome back students in-person to the lab this summer of 2021, with Charlotte beginning her upcoming thesis work precisely measure the strength of a particular atomic transition in lead, and two younger students, *Russell Blakey '23* and *Robin Wang '24* who are working to precisely measure isotopic differences in lead spectra using an infrared laser system.

Professor **Frederick Strauch** was delighted to be promoted and deeply honored to be named the William Edward McElfresh Professor of Physics. While he will never be as adept with an oscilloscope, he hopes to emulate the wisdom and wit of his predecessor. He continued as chair of the department and taught Mathematical Methods for Scientists (PHYS 210) in the Spring of 2019; he plans to limit his use of Zoom in the coming year.

Strauch continued his theoretical research in superconducting quantum circuits, quantum algorithms, and other applications to quantum information processing. His most recent work has addressed novel ways to encode, manipulate, and readout information in superconducting resonators, advanced coupling schemes for quantum circuits, as well as general topics in quantum information and dynamics. During the academic year, he worked with *Nico Coloma-Cook '21* whose thesis *Analysis of the Quantum Adiabatic Algorithm and Quantum Approximation Optimization Algorithm* studied theory and simulations of a novel hybrid algorithm to find solutions of hard optimization problems. They were joined for part of the year by *Skylar Chaney '20.5*, who had worked with the Chemical Physics Theory Group of Alan Aspuru-Guzik at the University of Toronto, studying continuous variable versions of the approximation algorithm. Strauch also supervised the thesis work of *Hyeongjin Kim '21* on *Optimal Control and Circuit Synthesis*, which completed the work from Strauch's Army Research Office for the study of "High Fidelity Quantum Logic Operations with Parametrically Coupled Transmon Devices."

During the Summer of 2021, Strauch and Ryan Watson simulated quantum circuits and ran experiments on the four-qubit superconducting quantum processors being developed by IBM, observing a violation of a special type of Bell inequality---a verification of entanglement between the qubits in this prototype quantum computer. Finally, his struggle to understand the philosophical implications of quantum theory with Keith McPartland in Philosophy continues; during the summer they, along with Bill Wootters and I*saac Wilkins '22*, enjoyed several discussions on decoherence and the Everett interpretation of quantum theory.

In the fall semester, Professor **David Tucker-Smith** taught Electricity and Magnetism (PHYS 201). In the spring, he taught the Particle Physics elective (PHYS 321) and helped out with the labs for Vibrations, Waves, and Opticts (PHYS 202) .

Tucker-Smith continued his research in theoretical particle physics. His recent focus has been on developing and studying testable models of baryogenesis, which attempt to explain the matter-antimatter asymmetry in the universe. During the summer of 2020, Tucker-Smith worked with *Justin Berman '21, Benny Weng '22* and *Jihoon Kim '22* on a theoretical framework that connects baryogenesis and dark matter. Justin continued with this research for his senior honors thesis and gave nice talks on his work at the April APS meeting and at Phenomenology 2021 Symposium. Justin is off to the PhD physics program at the University of Michigan in the fall. In the spring, Benny worked on related ideas for an independent study project. Jihoon and *Filip Niewinski '22* are currently working with Tucker-Smith as Summer 2021 research students and will continue as thesis students during the 2021-22 academic year.

In the summer of 2020, Professor Emeritus **Bill Wootters** offered a Zoom-based course, "Gravity", for the Osher Lifelong Learning Institute. This summer (2021), he will offer a new course for the same group, titled "Quantum Theory: Still Crazy after All These Years". The course will start with the history of quantum theory and continue through current ideas in quantum cryptography and quantum computing, finishing with a discussion of the best-known attempts to answer the question, What does quantum theory tell us about reality?

With a collaborator at Dartmouth, Bill is doing research toward expressing quantum concepts in terms of probability functions defined on a geometric structure known as discrete phase space. For decades, physicists have known how to formulate quantum theory on discrete phase space via "quasiprobability distributions," which can take negative values. Bill's work aims at replacing these distributions with genuine, non-negative probability distributions.

Post-Graduate Plans of Physics Majors

Name	Plans
Ilana Albert	Physics graduate program at Northeastern University
Justin Berman	Physics graduate program at University of Michigan
Declan Daly	Ph.D. program in experimental quantum physics at University of Maryland
Brendan Hall	Ph.D. program in biophysics at UCSF
Kim Hyeongjin	Ph.D program in physics at Boston University
Nelly Lin-Schweitzer	REU program at Georgetown University
Sophia Millay	Assistant staff in Homeland Protection Systems Group at MIT Lincoln Lab
Nicholas Patino	Ph.D. program in mechanical engineering at CU Boulder
Gabriel Patonette	Ph.D program in physics at Harvard
Joshua Reynolds	Ph.D. program in applied physics at Stanford
Paige Robichaud	Ph.D. program in physics at Harvard
Declan Smith	Ph.D. program in physics at Boston University

Physics Colloquia

[Colloquia are held jointly with the Astronomy Department.]

Daniel Aalberts
"Shooting the messenger RNA ==>-- mRNA vaccine technology"
The Spring 2020 Sigma Xi Lecture

Allison Carter '16, University of Maryland
"A Modular Quantum Computer with Trapped Ions and Single Photons"

Charlie Doret
"Missing Bats: Why the Curveball Curves, and How Fluid Flow Influences Sports"
Summer Physics Tea Talk, July 2020

"Searching for Dark Matter with Precision Measurements in Trapped Atomic Ions"
Summer Lunch Talk, July 2021

James Nolan, Williams College
"Atomic Doctors"

Duane Bailey, Williams College
"The Software-Hardware Dance: An Evolution"

James Whitfield, Dartmouth
"Welcome to Quantum: Moving from Mechanics to Engineers"

Ken Brown, Duke
"The Fault is in Our Qubits"

Heather Lewandowski, University of Colorado, Boulder
"Watching Chemical Reactions Happen One Molecule at a Time"

Ryan Trainor, Franklin & Marshall
"Galaxy Formation in Lyman-alpha or: How I Learned to Stop Worrying and Love Scattered Light"

Brian Shuve, Harvey Mudd College
"Illuminating Hidden Particles at Particle Colliders"

Vivienne Baldassare, Washington State University
"Searching for Supermassive Black Holes in Dwarf Galaxies"

Ilse Cleeves, University of Virginia
"Understanding Planetary System Formation Through Astrochemistry"

John Bollinger, NIST, Time and Frequency Div., Boulder, CO
"Quantum Simulation with Large Trapped-Ion Crystals"

Matteo Bucci, MIT
"A Perspective on Boiling Heat Transfer Experimental Research"

Off-Campus Physics Colloquia

Daniel Aalberts

"Improved Ribosome Profiling Debiasing Analysis Indicates Codon Translation Elongation Rates in E. Coli are Largely Uniform"
Poster by *Qiyuan Hu '20, Brendan W. Hall '21, Daniel P.G.H Wong '17*, Gregory Boel, John F. Hunt, and Daniel P. Aalberts. Cold Spring Harbor Translation Control Meeting, September 2020

Charlie Doret

"Isotope Shifts & Dark Matter Searches with Trapped Atomic Ions"
APS DAMOP Invited Talk, June 2021

Kate Jensen

"The Intriguing Mechanics of Soft Interfaces"
Invited talk, Thompson Hall Science and Mathematics Seminar, University of Puget Sound, April 2021

"Determining the size of individual colloidal hard spheres from tracking information"
Contributed talk, APS March Meeting, March 2021

"Elastocapillary Adhesion of Compliant Gel Microspheres"
Contributed talk, Annual Meeting of the Adhesion Society, February 2021

"Adhesion of soft gel microspheres"
Contributed talk, New England Complex Fluids Workshop, December 2020

"Starburst Instabilities, or What do the Matanuska Glacier and Milk have in common?"
Invited talk, "Zoomercolloiders" Seminar Series, November 2020

"Investigating the Role of the Gel Fluid Phase in Making and Breaking Adhesive Contacts"
Contributed Talk, ACS Colloids and Surface Science Symposium, June 2020

Catherine Kealhofer

"Generating and controlling ultrafast electron pulses for time-resolved electron diffraction"
Dartmouth College, Physics and Astronomy Colloquium (virtual), March 2021

Tiku Majumder

"High-Precision Measurements of Atomic Lead Transition Amplitudes and Static Polarizabilities"
DAMOP 2021 (virtual) meeting, June 2021

David Tucker-Smith

"Baryogenesis and dark matter from freeze-in"
Meeting of the ATLAS UEH working group (Unconventional signatures and Exotic Higgs), July 2020

Bill Wootters

"Quantum predictions arising from epistemically restricted classical predictions"
University of Campinas (lecture given remotely), July 2021

PSYCHOLOGY NEWS

The mural *Gold Cortex II* representing neurons in the motor cortex. This mural is positioned at the entrance to the large bright study area overlooking the science quad in the Psychology department. an additional view of the study space can be seen on page 86.

The psychology major at Williams College attracts a large number of students with diverse interests, goals, and backgrounds. Our students follow a curriculum that teaches them not only about what we know about mind and behavior, but also about how we know it, using experiential teaching as our core pedagogy. Students learn how to use the methods of scientific inquiry to critically evaluate information, generate new knowledge and imagine its implications and applications in the world. Students take a range of courses spanning the sub-disciplines of neuroscience, cognitive, clinical, developmental, and social psychology, as well as the psychology of education. Psychology faculty work closely with several interdisciplinary programs, including Neuroscience, Cognitive Science, Program in Teaching, Justice and Law, Women's, Gender, and Sexuality Studies, and Public Health.

During the 2020-21 year, the pandemic inspired psychology faculty to rethink their teaching. Some classes were offered entirely remotely, others were offered predominantly in-person (with necessary social distancing), and many were offered in hybrid formats that found some students attending in person and others via Zoom. Faced with these new challenges, psychology faculty developed new strategies to engage students and create successful classroom experiences.

The psychology department prides itself on introducing students to empirical research. Students in research seminars routinely design and conduct behavioral experiments. Senior thesis students, with the support of their faculty mentors, develop sophisticated year-long projects that culminate in the end-of-year thesis presentations; many thesis projects ultimately are presented at professional meetings or published in journals. Despite the challenges of remote/hybrid instruction, social distancing requirements, and limits on the time available for labs, students continued to conduct high-quality research projects. In 2020-21, five students completed honors research projects (abstracts for these projects can be found in the Student Thesis Abstracts section of this report) and many more conducted independent studies and worked as research assistants.

Thesis student *Matan Levine-Janach '21* received the newly named Chuzi-Ianniello Prize in Psychology (formerly the G. Stanley Hall Prize). The prize is awarded to the graduating student who has demonstrated exceptional achievement in research and who has contributed meaningfully to the intellectual community of the psychology department. Matan's project included several experiments that integrated theoretical work on social norms with the applied issue of anti-gay prejudice that is often fueled by social media and the echo chambers they tend to create around political divides. Throughout his time at Williams, Matan was an active student in the psychology department, working in several different labs and being a leader within the Student Liaison Committee.

The psychology department Student Liaison Committee collaborated with faculty to develop a collection of resources for students that are now available on the departmental Glow page. Using newly honed Zoom skills, faculty and students produced presentations on graduate training in psychology, career paths and options, post-BA research opportunities, and fellowships. We are pleased to have this wonderful collection of resources available to students.

The psychology department was thrilled to welcome several new faculty members including Assistant Professor Victor Cazares. Victor studies the neural systems underlying learning, memory, and forgetting and has established a cutting-edge laboratory to pursue these topics. In addition to his research, he taught courses ranging from Introductory Psychology to a senior seminar. His research seminar, "From Order to Disorder," examined how genetic and environmental factors shape brain and behavior. We also welcomed Visiting Assistant Professor Jeremy Simon who taught Experimentation and Statistics (PSYC 201) and shared his expertise on prejudice and strategies for reducing it as part of his research seminar.

During the summer of 2021, the psychology department experienced two big moves. First, we moved physically from our temporary building on Stetson Court to the beautiful, new Wachenheim Science Center. Psychology faculty are eager to embark on new research questions in their state-of-the-art laboratories and to teach in the flexible classrooms. A spacious great room overlooking the science quad welcomes students for conversation, study, and socializing. This move to a new building coincided with the psychology department's official move into Division III: Science and Mathematics. This move recognizes the department's scientific and empirical orientation; its long-standing relationships with other Division III departments; and the content, goals, and methods of our courses.

The Psychology department was greatly saddened this year with the death of Professor Emeritus Phebe Cramer on April 2, 2021. Phebe joined the faculty in 1970 as only the fifth woman on the faculty campus-wide and the first in the Psychology department. She went on to teach for nearly four decades and remained an extremely productive researcher and author well after her retirement in 2009. Phebe was a treasured member of the Pshychology department as well as the greater Williams community and her loss is keenly felt.

A vibrant Class of 1960 Scholars Program brought four speakers to share their work with the 22 participating students. Topics included motivated reasoning and the biases people bring to bear on new information (Pete Ditto), the phenomenological states associated with memory errors (Sharda Umanath), the neurobiological mechanisms underlying sensory experiences of touch and pain perception (Prof. Ishmail Abdus-Saboor), and the impact of modern globalization and acculturation on the development of well-being in children and families (*Gail Ferguson '01*).

Class of 1960 Scholars in Psychology	
Ginger Atwood	Isabel Rosenberg
William Cozadd	Helene Ryu
Olivia Dulany	Victoria Saltz
Caroline Galo	Amanda Shapiro
Gigi Gamez	McKenzie Stoker
Gabrielle Granata	Simone Veale
Bariki Innis	Clarissa Wallin
Nigel Jaffe	Laura Westphal
Andrew Lee	Kathryn Wright
Matan Levine-Janach	Neema Zarrabian
Anjali Poe	Patrick Zhuang

Assistant Professor **Victor Cazares**, a new professor in the Psychology Department, opened his lab in June 2020. His research is deeply motivated by the great socio-economic burden posed by psychiatric disease on society worldwide. Furthermore, he is driven to perform investigations that stimulate the development rate of new treatments for psychiatric disorders, which currently lags significantly behind other disease states. The Cazares lab is specifically focused on studying how genes and the environment interact and change the brain to determine risk or resiliency for psychiatric disease. To achieve this, our lab compares the behavior and the properties of the brain of distinct types or strains of mice, each which is genetically unique. For example, some of the mice innately behave more "anxiously" while others may be more uninhibited. Using these behavioral differences, the Cazares lab then examines which genes and brain regions determine risk or resiliency for disorders such as depression, anxiety, or schizophrenia. Their ultimate goal is to identify the factors that underlie that predict or protect individuals from psychiatric illness with the hope that their findings will stimulate the development of new therapeutic approaches.

In his first year, Cazares recruited a team of five excellent students from who are actively conducting experiments and collecting data. He published two research articles. One, in the fall of 2020, (Rodriguez et al., 2020) describes how mice which are genetically predisposed to be susceptible to stress, also exhibit changes in their motivation for reward and ability to learn and remember. His lab also contributed to the validation of a new open-source, 3D-printed tool that can evaluate reward learning in the mouse's home cage and in the absence of the experimenter, thus enabling, highly-precise, long-term behavioral measurements (Matikainen-Ankney BA et al., 2021). Currently, his lab is focused on comparing how the brain of anxious and non-anxious mouse strains changes when the animals are taught to suppress fear memories.

Gwyneth Maloy '21 characterized the ability of different mouse strains to suppress fear memories. she helped develop many of the protocols that Cazares lab now uses to visualize brain activity that is associated with learning and was the first student to conduct experiments in the Cazares lab. Gwyneth received highest honors in psychology, was invited to join the Sigma Xi society and will be starting at Yale Medical School in Fall 2021.

Associate Professor **Jeremy Cone** completed his sixth year in the Psychology department. In 2020-21, he published 3 new papers. The Implicit Cognition and Evaluation (ICE) lab continued to be quite active this year. One student, *Sarah Baldree '21*, conducted a thesis in the lab on the predictors of durable revision of implicit impressions of other people; *Angela Wang '22* completed independent studies in both the Fall and Spring semesters; *Jennifer Hickey '21, Sam Mermin '22,* and *Gaston Aime '23* served as research assistants for the full academic year. And finally—and perhaps most exciting—the ICE lab moved to its new space in the Wachenheim and had its first in-person lab meetings in over a year: *Niki Srivastava '23, Victoria Pysher '22, Sam Mermin '22, Keyly Barrios Morales '23, Cailin Stollar '22,* and *Gaston Aime '23* all participated in an in-person summer science research this year. Sam in particular, deserves recognition for his exceptional bowling performance in our first official lab outing since pre-pandemic. For more information about the lab and what we're currently up to, check out: http://jeremycone-icelab.com.

In January, Professor **Susan Engel** published a new book, *The Intellectual Lives of Children* (HUP 2021). She reviewed scholarly articles for *Science Education,* and *Child Development*, Harvard University Press, and Oxford University Press, as well as research proposals for the Templeton Foundation and NSF and NICHD. In addition, she gave a keynote presentation at an international education collaborative, Seedlings, in New Haven, CT. She and *Whitney Sandford '20* presented research on young children's capacity to invent at the Annual Meeting of the Eastern Psychological Association, as well as at the Biennial Conference of the Society for Research in Child Development. Engel continues to serve on the board of Planet Word, a new museum of language in Washington DC.

As this entire academic year spanned the COVID-19 pandemic, it was anything but a typical year, in so many ways. At the same time, there were some of the "usual" activities. Professor **Laurie Heatherington** was on leave in Fall 2020 and continued her research and writing on family therapy change processes and psychotherapy in general. She and her student collaborators *Peter Barry '21, Mariane St. Juste '21,* and *Theresa Morley-McLaughlin '21*, finished and submitted a large study of Williams first year students, revisiting and extending some classic findings from her lab and others, on the tendency of women to be overly modest in the self-presentation of their achievements. With two other student research collaborators, *Gabrielle (Gabs) Ilagan '18* and *April Su '23*, she submitted new two studies extending Gabs' honors thesis research on preferences for a racial and gender match with their psychotherapists and the role of empirical research on the effects of information about whether matching affects therapy outcomes, in their preferences.

In June 2021, Gabs presented a paper based on this research at the International Society for Psychotherapy Research, based (remotely) in Heidelberg, German, with Heatherington in attendance at 3:30 a.m. Eastern time! In summer 2020, she supervised *Matan Levine-Janach's '21* Summer Research Fellowship; their study on religion, politics and psychotherapy (following up on his empirical project in her Spring 2020 research seminar) was accepted for presentation as a poster at the 2021 Association for Cognitive Behavior Therapy conference.

With *Chanel Zhan '16* and Math/Stats Professor Bernhard Klingenberg, she published "Disordered eating- and exercise-related behaviors and cognitions during the first year college transition" in the *Journal of American College Health*. Results included the finding that varsity athletic participation and basing a lower amount of one's self-worth on appearance were protective against subclinical disordered cognitions and behaviors. This article was based on Chanel's senior honors thesis. In November, she presented a Science Center Lunch Talk, "Telling others and thinking privately about grades: The role of gender and first generation college status."

Fall semester also found Heatherington volunteering at the college testing site and providing evidence-based advice about how families could avoid conflict while navigating the COVID pandemic decisions and restrictions.

In the spring semester, she enjoyed Round 2 of "adventures in remote learning," teaching her 15-student Psychotherapy: Theory and Research (PSYC 355) course, with accompanying lab, totally online. At the very end of the semester, it was a joy to meet in person in the beautiful new Wachenheim Science Center with small groups of students, for consultation on data analysis and interpretation for their empirical projects.

Heatherington served on the Editorial Boards of *Psychotherapy Research; Journal of Family Psychology; Journal of Marital and Family Therapy;* and *Psychotherapy*: *Theory, Research, Practice, and Applications*. She served on the Directors and Associates Board, and chaired the Program Committee of Gould Farm, a treatment center/working farm in Monterey, MA, which serves people with schizophrenia and other serious mental illness.

Assistant Professor **Shivon Robinson** completed her second year of teaching at Williams this year. Despite the many challenges brought on by the COVID-19 pandemic, her lab remained active, in large part due to the hard work and dedication of student researchers.

This past year, she was invited to give two talks; she presented work from recently published papers at the Capital Region Neuroscience Colloquium Series at Albany Medical and the Center for Depression, Anxiety and Stress Research Speaker Series at Harvard Medical School. Lab alumna *Carmen Bango '20* also presented work from her independent study in a poster titled "Long-term Effects of Early Life Morphine Exposure on Development, Affect and Cognition" at the Society for Neuroscience annual meeting.

Three students completed honors theses in her lab this year: Using mouse models, *Daniel Hahn '21* explored the potential therapeutic effects of nor-binaltorphimine, a long lasting kappa opioid receptor antagonist, on opioid withdrawal induced sleep disturbances; *Simone Veale '21* investigated whether perinatal exposure to opioids confers risk to altered drug responses later in life; and *Andrea Orozco '21* sought to determine the effect of perinatal and adolescent morphine exposure on cognition and neurogenesis. Additionally, *Theresa Morley-McLaughlin '21* completed an independent study in the lab investigating the effects of buprenorphine, a drug currently FDA approved to the treat opioid use disorder in human adults, on withdrawal symptoms in morphine-dependent neonatal mice. Several research assistants, including *Victoria (Tori) Saltz '22, Grace Reynolds '23, Kasey Stern '21, Nat Davidson '22,* and *Mia Holtze '23*, helped to bring these and other projects to fruition this year. For more information and updates on the lab check out the website: https://sites.williams.edu/sar1/.

Professor **Noah Sandstrom** has continued his research examining environmental and biological factors that shape outcome following mild brain injuries. Working with a thesis student, *Adrienne Conza '21*, and in collaboration with Victor Cazares, he has been examining how repeated concussive impacts to the head alter the performance of mice on a battery of behavioral and cognitive tasks and how these changes are reflected in the neuroimmune responses within the brain. In addition, Sandstrom and former student *Masen Boucher '20* presented research conducted during her senior year at the annual meeting of the National Neurotrauma Society. Masen was awarded a Trainee & Diversity Award based on her submission.

While the pandemic restrictions limited opportunities for in-person outreach, Sandstrom managed to make a virtual visit to the third-grade students at Pine Cobble School where he introduced them to the exciting field of neuroscience and did his best to answer their amazingly challenging and profound questions.

Visiting Assistant Professor **Stephanie Steele** and her lab group, the Behavioral Assessment of Self-Injury Lab (BASIL), have continued their work over the past year to further understand the feasibility and acceptability of app-based skills training for adults with past-month non-suicidal self-injury (NSSI). This work has continued under her current NIH Clinical Research Loan Repayment Program Award (LRP; L30 MH120630), with some modifications due to COVID-19 restrictions (namely, a shift to online data collection only). During summer 2020, her Summer Science Program students, *Nigel Jaffe '22* and *Cailin Stollar '22,* continued the design and development of their cognitive-behavioral skills training app. They began online study recruitment to begin testing the app, which primarily occurred via social media pages and groups related to mental health, self-injury, and related disorders (e.g., borderline personality disorder support groups). As part of their general screening survey for this study, they also collected data to further understand how aspects of identity, such as race, sexual orientation, and gender identity, potentially impact performance on one of their primary study measures, the Self-Injury Implicit Association Test (a computer-based test that they use to examine implicit identification with self-injurious behaviors). Data from this project will be presented at the Association for Behavioral and Cognitive Therapies (ABCT) convention by current BASIL student research assistant *Edward Wolfson '23* in the fall of 2021 in New Orleans, LA. Additionally, during the spring 2021 semester, Nigel Jaffe completed an independent study project under Steele's mentorship that focused on usage of and attitudes toward mental health/wellness teletherapy services on campus; Nigel will present this quantitative data in a research poster presentation at ABCT in the fall of 2021.

Nigel won two awards at Williams based on his work in BASIL. In the fall of 2020, Nigel was awarded the Williams Bicentennial Psychology Summer Fellowship for his research in the Summer Science Program 2020, where he focused on app development for the above-mentioned study, and completed a literature review on teletherapy to inform the independent study he completed during the spring 2021 semester. Nigel was also awarded The Roche Student Research Fund to complete qualitative interviews during summer 2021 as an extension of his spring 2021 independent study project on college students' attitudes towards and usage of teletherapy services on campus. This additional data collection will allow for mixed methods data analysis and interpretation of study results, which will be presented at the upcoming North American Chapter of the Society for Psychotherapy Research annual conference in the fall of 2021.

Steele along with Nigel Jaffe and *Grace Murray '20* are also collaborating on an invited book chapter for *The Handbook of Nonsuicidal Self-Injury* (Oxford University Press) based on Steele's work that has focused on social contagion and NSSI. The handbook is set to be published in December 2021. Additionally, Steele continues to serve as the Associate Editor of *The Clinical Psychologist*, the official journal of Division 12 (Society of Clinical Psychology) of the American Psychological Association. She also continues to serve as an ad hoc reviewer for several peer-reviewed journals, including most recently, the *Journal of Psychiatric Research*. In the spring of 2021, she completed all licensure requirements, and is now a licensed clinical psychologist in the state of Massachusetts. Although she is not currently practicing or doing any clinical work, the license serves her well in her research. And this summer, she developed a new 300-level seminar for the Psychology Department at Williams entitled, High-Risk Behaviors in Psychopathology: A Transdiagnostic Approach to Treatment and Research, which will be taught for the first time this fall. This is a seminar that intends to combine a clinical perspective on high risk behaviors (based on case studies and Steele's clinical work) with the current empirical literature to understand what science-based treatments we have available, and how risk and safety are managed in clinical settings when patients present with these types of behaviors (e.g., substance abuse disorders, NSSI, disordered eating).

In the Fall of 2020 she submitted a grant application to extend her current LRP Clinical Research Award from NIH to allow for continued work on self-injurious thoughts and behaviors and identity.

Additionally, Steele and members of her lab presented three research posters virtually at two different conferences in November 2020. Nigel Jaffe and Prof. Steele presented a poster on the relationship between functions of NSSI and identification with NSSI at ABCT's Suicide and Self-Injury Special Interest Group poster session; Grace Murray and Prof. Steele presented a poster in ABCT's general session on adolescent bullying and NSSI; Finally, Nigel and Steele presented a poster at the New England Psychological Association (NEPA) Annual Meeting focused on predictors of implicit associations with NSSI.

Associate Professor **Catherine Stroud** continued her research program focusing on stress, interpersonal relationships, and the development of psychopathology among adolescents and young adults. During the 2020-21 academic year, she began the third follow-up of a longitudinal study examining biological, psychological, interpersonal, and environmental factors that affect risk for psychopathology among female-identifying young adults. In collaboration with her students *Anjali Poe '22; Helene Ryu '22,* and *April Su '23*, Stroud developed the third wave to elucidate predictors of risk and resiliency in the face of pandemic-related stress. April was selected as an Allison Davis Research Fellow. Over the next 2 years, under Stroud's mentorship, April will examine the role of coping and emotion regulation strategies in shaping sensitivity to depression during the COVID-19 pandemic. At the annual conference of the International Society of Psychoneuroendocrinology, Stroud co-chaired an oral symposium focused on understanding the interplay of the environment and physiological stress processes in shaping later health outcomes. In addition, at the conference, Stroud presented a paper demonstrating that the tendency to overestimate self-blame for uncontrollable stressful life events was associated with lower latent trait cortisol, a risk factor for the development of psychopathology. This paper built upon *Blair Curzi's '14* independent study project. At the same conference, Stroud presented a collaborative paper examining the interplay of different types of stressors in the development of depression and anxiety among youth. Along with her colleagues, Stroud also co-authored a manuscript documenting an association between dopaminergic genetic variation and reward-related personality measures in 2 samples of early adolescents. In the spring, Stroud presented her work as part of the 2021 Faculty Lecture Series at Williams College.

Post-Graduate Plans of Psychology Majors

Sarah Baldree	Patient Care Coordinator at CCRM Fertility Boston
Will Barrett	Staff member at Camp Dudley, a sleepaway sports camp in Westport, NY
Peter Barry	Growth Analyst at Lunar Solar Group, a Marketing Consultancy in NYC
Alexandra Bernard	Health Care Recruiter in the Boston area
Cameron Carver	Analyst at a venture capital firm
William Cozadd	Pursuing a position in nonprofit advising or consulting
Hallie Della-Volpe	Math teacher for Teach for America in New Orleans working in special edu-cation
Olivia Dulany	Joining Teach for America in Hawaii
Caroline Galo	Looking for a psychology research position in NYC
Daniel Hahn	Research Assistant at NCAN in the Albany VA Medical Center
Kenneth Han	Starting medical school at USC Keck School of Medicine in Fall '21
Jennifer Hickey	Looking for a clinical research position
Bariki Innis	Working in Asset and Wealth Management Solutions in NYC
Edwin Lantigua	Software Engineer at General Dynamics
John Lautenbach	Looking for a position in marketing
Long Le	Working for a Management Development Program
Matan Levine-Janach	Clinical Research Coordinator at the Dauten Family Center for Bipolar Treatment Innovation at Massachusetts General Hospital
Kennedy Long	Community Associate for Waeve in Boston
Gwyneth Maloy	Starting medical school at Yale School of Medicine
Henry Marquardt	Working in Boston at Liberty Mutual in Analyst Development Program
Elle Montoya-Kelner	Applied for a teaching position in Japan
Camille Nance	Hope to be working in advertising or marketing
Justin Nelson	Working in operations for General Motors in Mississippi
Jamie Nichols	Looking to do either community mental health work or work for a radio station/podcast in Boston
Daniel Ortiz	Would like to work in School Admissions
Amanda Shapiro	Business Analyst at the Seurat Group, doing management/strategy consult-ing for consumer-packaged goods

Mariane St Juste	Working in a neurodevelopment lab at Northeastern University
Danielle Sturm	Working in management consulting in Atlanta
Jessica Thompson	Starting Master of Arts in Teaching for Classics (Latin) at Indiana University Bloomington
Simone Veale	Research Assistant at the Psychiatry Neuroimaging Laboratory (PNL) at Brigham and Women's Hospital/Harvard Medical School
Allie Weiner	Recruiter at Phaidon International
Laura Westphal	Research Associate at the Fenway Institute in Boston conducting healthcare research for the LGBTQ population and those affected by HIV with an emphasis on community engagement and care
Sarah Willwerth	Clinical Research Assistant in orthopedics/sports medicine at Boston Chil-dren's Hospital
Abigail Yu	Working at Hoffman Alvary, a financial consulting firm in Newton, MA
Neema Zarrabian	Working in Media Buying and Planning at VaynerMedia in NYC
Patrick Zhuang	Lab Research Assistant at Dana Farber Cancer Institute in Boston

A view of the Psychology department study area overlooking the science quad in the new Wachenheim Science Center. Areas such as these, which are scattered throughout the science buildings, provide students with amazing spaces to work and collaborate.

Psychology Colloquia

Pete Ditto, School of Social Ecology at the University of California, Irvine
"Through the Partisan Looking Glass: The Social Psychology of Political Polarization," March 3, 2021

Sharda Umanath, Claremont McKenna College
"Is There a Difference Between I Don't Know and I Don't Remember? Phenomenological States Associated with Retrieval Failures," March 16, 2021

Ishmail Abdus-Saboor, University of Pennsylvania
"Mouse Pain Scales and Neural Circuits for Social Touch," March 31, 2021

Gail Ferguson '01, University of Minnesota
"The Americanization of Global Youth Identity and Lifestyle Habits Through Remote Acculturation," April 13, 2021

Victor Cazares
"Failure in Memory Encoding Leads to an Emotional Bias"
Williams Science Colloquium, Fall 2020

Off-Campus Psychology Colloquia

Victor Cazares
"Using Strain Specific Phenotypes to Elucidate Mechanisms Underlying the Reduction of Persistent Fear"
Invited Seminar, Jackson Laboratories, Bar Harbor, ME

Shivon Robinson
"Pharmacological Mechanisms Underlying the Antidepressant and Anxiolytic Effects of Buprenorphine"
Center for Depression, Anxiety and Stress Research Speaker Series, Harvard Medical School, March 3, 2021

"Neurobehavioral Effects of Early Opioid Exposure in Mice: Influence of the OPRM1 SNP"
Capital Region Neuroscience Colloquium Series, Albany Medical College, September 30, 2020

"Long Term Effects of Early Life Morphine Exposure on Development, Affect and Cognition,"
Poster presented virtually with *C.I. Bango '20, D. Hahn '21, G. Maloy '21, K. Stern '21, S. Veale '21, G. Reynolds '23*
Society for Neuroscience, Virtual Conference, January 2021

Noah Sandstrom
"Time Course of Behavioral Deficits Following Single and Repeated Moderate Traumatic Brain Injury"
Presented with *M. Boucher '20*
National Neurotrauma Society, Virtual Sumposium, July 2021

Catherine Stroud
"Overestimating Self-Blame for Stressful Life Events and Adolescents' Latent Trait Cortisol: The Moderating Role of Parental Warmth"
Paper presented with F. R. Chen, *B.E. Curzi '14*, D. A. Granger & L. D. Doane
Co-chair Oral Symposium at the annual conference of the International Society of Psychoneuroendocrinology, August 2020

"Effects of Early, Daily, and Physiological Stress on the Development of Internalizing Symptoms in Middle Childhood"
Paper presented with E.K. Lecarie, L. D. Doane, M.C. Davis, K.J. Grimm, & K. Lemery-Chalfant, Annual conference of the International Society of Psychoneuroendocrinology, August 2020

HONORS THESES

Each year, many students elect to complete a thesis in their major. Students begin work generally in the summer prior to their senior year and engage in a rigorous course of study guided by their faculty advisor. The culmination of this work is a poster presentation in the spring which is open to the public, and the publication of the thesis which is archived by the college. This work feeds into future students' research efforts and often leads to co-authorship in peer-reviewed papers.

On the following pages are abstracts outlining the work of our student researchers. For many of our former students, the publication of their thesis was the first in a long list of professional publications in a successful career in science. I have no doubt that many of the names in this section will follow their predecessors on this path.

Astronomy

Investigating the Vertical Structure of Turbulence around DM Tau
Amina Diop

Turbulence is one of the key processes influencing planet formation in protoplanetary disks, but we still do not know the physical mechanism that is driving it. In this thesis, we sought to determine the vertical structure of turbulence, which could shed light on this mechanism. We have been working with the disk around DM Tau, since it is so far the only system where significant non-zero turbulence has been robustly detected in its upper layers using CO emission. To estimate turbulence near the midplane in the outer disk, we used ALMA observations of N_2H^+(J=3-2) and DCO^+(J=4-3) alongside a ray-tracing radiative transfer code with a parametric model of the disk structure and Markov Chain Monte Carlo (MCMC) methods. The N_2H^+ emission extends from ~ 29 to 390 au and peaks at ~105 au. We note that the inner edge of the emission does not match the previously determined inner edge location (~ 75 au). This discrepancy is explained by the fact that our data has a higher sensitivity, which allow us to see the faint emission close to the star. The location of the inner edge suggests that the CO snowline could either be at ~ 75 au and that CO depletion is responsible for the production of N_2H^+ interior to the snowline, or that the CO snowline is closer to the star than previously measured. We also showed that N_2H^+ is optically thin and that it arises from less than 1 pressure scale height above the midplane, which confirms that it is a tracer of the midplane conditions. As for DCO^+, it has a centrally peaked emission with extended emission characterized by a depletion between ~ 104 and 156 au. The intricate structure of the DCO^+ emission could be due to various processes, including its multiple formation pathways, CO freeze-out, UV non-thermal desorption, dust obscuration, and radial migration of dust grains. The DCO^+ preliminary models suggest that the observed emission is best reproduced by a combination of the warm and cold formation pathways where the two pathways have unequal abundances in addition to non-thermal desorption in the outer disk. Moreover, by analyzing the peak-to-trough ratio, we were able to conclude that the midplane is likely characterized by turbulence levels below that of the upper layers, which suggests that turbulence is either driven by the magnetorotational instability or the vertical shear instability. Our current MCMC results could not help us constrain model parameters (including turbulence) tightly because the walkers did not fully converge by the end of the run. The model generated using the MCMC results shows emission extending from ~ 21 to 380 au and peaking at ~96 au, which is comparable to the observed emission. However, the model underestimates the flux in the outer disk.

High Resolution Spectral Analysis: Investigating the Nebular Kinematics of Green Pea Galaxies J1735 and J0851
Patricia Fofie

Green Pea galaxies (GPs) are considered analogues to early galaxies during the Epoch of Reionization ($z > 6$) because of their Lyman continuum (LyC) and Lyman alpha (Lyα) emission. Studying the kinematics of GPs can afford us insight into the mechanisms responsible for the escape of LyC and Lyα radiation in these star-forming galaxies. Green Peas have broad spectral emission line wings that suggest fast gas motions, but the physical origin of these broad wings is still unknown. To gain more insight into the cause of these wings and possibly into the mechanism that allows for LyC escape in these galaxies, we analyze high resolution spectra of GPs J1735 and J0851 from the

ARC Echelle Spectrograph. We conduct flux comparisons, photoionization source analysis, and velocity analysis to investigate the nebular kinematics of these GPs. We find that the broad wings are highly symmetric and Lorentzian shaped with no clear indication of outflows or shocks opposing the supernova shock theory of LyC escape. Additional investigations into the physical origins of the best fit model indicate that the Lorentzian component cannot only be from collisional broadening and that a catastrophic cooling mechanism is likely present in these GPs but will require further investigation.

Time Projection Chambers: Background Simulations and Argon Purification for a Low-Mass WIMP Search

Duncan McCarthy

There is abundant indirect evidence that the universe is filled with non-baryonic dark matter. As limits on the dark matter mass and cross section get restrictive, direct detection exper- iments are increasingly interested in understanding backgrounds at lower energies. The Giovanetti lab has made progress towards simulating and analyzing background sources in a liquid argon detector in the sub GeV/c2 WIMP dark matter regime. Using GEANT4 and the ROOT data analysis framework, we have successfully demonstrated a detector response reconstruction algorithm along with three analysis algorithms for reducing background events: a multi-scatter cut, primarily targeting high energy gammas; a fiducialization cut, targeting alpha and beta particles; and an active veto cut targeted at neutrons. Our work provides the foundation for higher statistics simulations with an array of background particles that will be used to optimize detector geometry and material choices.

In parallel, we have begun fabricating an argon purification and condensation loop that will be used for research and development of dual-phase argon time projection chamber detectors. We have demonstrated a feedback control system that will precisely control the pressure inside the detector chamber by controlling the condensation rate of gaseous argon. Along with designing and building a frame, gas manifold, and science chamber feedthroughs, we have machined a small, single-phase argon detector that will house two sensitive silicon photomultipliers. In the near future, we hope to verify the system by measuring signal response as a function of argon purity as the concentration of impurities are reduced over time.

Biology

Upper thermal tolerance differs across life stages in Trinidadian guppies (*Poecilia reticulata*)

Brianna Bourne

Upper thermal tolerance is thought to reflect a population's ability to persist in the face of extreme heat events, like those associated with climate change. To date, most comparisons of thermal sensitivity and subsequent vulnerability are based on species means, with upper thermal tolerance usually measured only in adults. However, there is increasing evidence that thermal tolerance may differ across life stages. Of the studies that do test upper thermal tolerance across individuals of a population, rarely do they test and compare more than two different life stages. Accounting for stage-specific variation could help further refine predictions of population resilience in the face of climate change. Upper thermal tolerance may be determined by oxygen capacity and limitation caused by increasing metabolic demand at higher temperatures. Life stages that have an underdeveloped cardiorespiratory system (as in young individuals) or increased metabolic demand due to egg production and/or embryo care (as in reproducing individuals) should therefore be the most vulnerable. In this study, I examined upper thermal tolerance in five different life stages of Trinidadian guppies (*Poecilia reticulata*): newborns, juveniles, virgin females, pregnant females, and mature males. I found that the critical thermal maximum was the highest in juveniles, followed by newborns, pregnant females, virgin females, and then males. Oxygen limitation and increased metabolic load cannot exclusively explain these results, suggesting that other physiological processes are associated with upper thermal tolerance. Although it is currently unclear what mechanisms are responsible for these underlying differences, these results suggest that differential vulnerabilities should be considered when predicting how populations will respond to climate change.

Characterizing the Pangenomes of Key Oceanic Microbiome Community Members

Kiersten Campbell

Prochlorococcus marinus and Pelagibacter ubique are dominant oceanic microbes that play crucial roles in global carbon and energy cycles. We hypothesize that differences in genomic content connect to potential adaptive differences that enable these lineages to co-occur and thrive in the oceans. In order to address this hypothesis, this project conducted novel, large-scale comparative genomic analyses. Investigation into genes unique to each genus revealed differences in key metabolic and environmental response pathways, suggesting that the two lineages have evolved distinct and efficient strategies for utilizing resources in their environment. Additionally, this project characterized the pangenomes of each lineage, demonstrating the impressive genomic diversity contained within the individual lineages. Taken together, by characterizing the genome content within and across Prochlorococcus and Pelagibacter, we illustrate many ways through which the two lineages are able to dominate, yet still co-occur, in marine environments.

The Effects of Social Isolation on Behavioral and Neuroimmune Response to Mild Traumatic Brain Injury (mTBI)

Adrienne Conza

Mild traumatic brain injuries (mTBI) are a major health problem in the United States, with both acute and long lasting effects on the physiology of the nervous system and associated cognition and behavior. Decreased social interaction is ubiquitously prescribed as part of treatment for mTBI; at the same time, it is well understood that social isolation is a stressor in both humans and animals (Jones, 2011; Mumatz, 2018). However, little-to-no research has evaluated how stress associated with social isolation impacts recovery from mTBI. Thus, this project investigates the behavioral and neuroimmune consequences of both social isolation and mTBI in mice. Deficits in memory are common after mTBI, particularly in tasks requiring hippocampal function, so, I began by establishing a fear conditioning protocol in order to assess the effects of mTBI on a hippocampal-mediated task. To assess the effects of mTBI and social isolation on this fear conditioning task, mice received two closed head injuries using a closed head injury protocol that induced increased latency to right compared to sham animals. Mice were then either group housed or singly housed for two weeks prior to contextual fear conditioning. During fear conditioning a mild footshock was paired with a specific context (context A) for 2 days, followed by three days of context testing where mice were placed in a novel context (context B) on the first day and context A without foot shocks on days 1-3. Mice displayed acquisition of fear, and during the second day of fear conditioning, impacted mice froze significantly less than sham mice. Mice also showed discriminatin between context A and the novel context B, with significantly more freezing in context A. Mice also showed extinction, as freezing decreased across the three days of context testing. Impact condition had no significant effect in discrimination or extinction, and housing had no significant effect on any of the behavioral measures. IBA-1 staining was used to visualize neuroimmune response, and increased IBA-1 was found only in the ipsilateral frontal cortex of impacted mice. IBA-1 staining was not found in sham mice or in the hippocampus of impacted mice. Future studies could include a frontally mediated behavioral task or could shift the location of impacts to the hippocampus to see more significant effects of impact on behavior, and changing the timeline of the study could potentially lead to a significant impact of housing on behavior and neurimmune response.

Characterizing the FKBP5 Gene in the Stress Response of *Danio rerio*

Erin Courville

The FKBP5 gene, encoding the immunophilin FK506-binding protein 51 (FKBP5), has been implicated in numerous psychopathologies based on both polymorphisms within the sequence and based on epigenetic variation. FKBP5 is a prominent actor in the stress response through its role in glucocorticoid receptor (GR) signaling, in which FKBP5 complexes with the GR to regulate its nuclear translocation and subsequent transcriptional activity in response to the glucocorticoid cortisol, the product of the signaling process of the hypothalamic-pituitary-adrenal (HPA) axis. FKBP5 functions in this process in concert with FKBP4, as well as other similarly structured immunophilins such as PPID that, when bound to the GR in place of FKBP5, facilitate translocation of the GR-glucocorticoid complex to the nucleus. While the relationship of these GR signaling genes and stress has begun to be examined in prospective studies with human patients, these studies have yet to be recapitulated in the Danio rerio (zebrafish) model system, which employs a homologous stress response system to that found in humans. This study begins to characterize the role of the FKBP5 gene in its relationship to the expression of FKBP4 and PPID in response to stress (established by treatment with dexamethasone at four days post fertilization) by qPCR studies comparing mutant FKBP5 genotypes imposed on a transgenic background construct (SR4G-GFP:BH). Additionally, we evaluate the methylation states of CpG Island 5 within the FKBP5 gene in response to stress in embryonic samples and in adult zebrafish by bisulfite conversion and bacterial transformation, though no differences in sequence were notable. Our results suggest that while FKBP5 genotype does not affect the expression of FKBP4, it remains possible that there is an effect on the expression of PPID, positing a potential dynamic means of regulation between components of the stress response system.

Investigating the Mechanisms Through Which the Type 6 Secretion System Modulates Plant Defenses in *Arabidopsis thaliana* Seedlings

Rachel Cross

Agrobacterium tumefaciens is a bacterial strain that commonly infects plants to cause crown gall disease. The Type 6 Secretion System (T6SS) is a crucial part of this process, where the *A. tumefaciens* T6SS secretes at least three known effectors that influence host plants. In the Banta lab we are focusing on the relationship between *A. tumefaciens* and the plant line *Arabidopsis thaliana*. The presence of the T6SS allows the bacterium to dampen host defense responses to increase tumorigenesis. There are many genes involved in the *A. thaliana* defense system, such as abscisic acid (ABA) and IMPAIRED OOMYCETE SUSCEPTIBILITY1 (IOS1). Previous research has shown that both the T6SS and IOS1 negatively regulate ABA signaling to dampen plant defenses. With this knowledge, we looked to determine how T6SS and IOS1 may be interacting to attenuate ABA signaling, as well as whether *A. tumefaciens* functions more like a bacterium or an oomycete. We found that T6SS is likely working through IOS1 to reduce ABA signaling and dampen host defenses. Additionally, *A. tumefaciens* was observed to act more like an oomycete rather than a bacterium due to *A. tumefaciens* causing greater infection in *A. thaliana* ios1 mutants than wild type plant lines. Future thesis research should focus on further elucidating the mechanism behind how T6SS may act through IOS1. This can be done by comparing the time course of ios1 mutants and wild type plants through monitoring defense genes, MAPK activation, and measuring ABA levels.

Investigating the importance of neurons that express both teashirt (tsh) and julius seizure (jus) in altering seizure sensitivity

Cassie Deshong

Drosophila melanogaster is an excellent model organism for genetic experiments. Previous research proposed the *Drosophila* gene julius seizure (jus) as a suitable model to study the development of epilepsy (i.e. epileptogenesis). jus expression is critical for normal neuronal function. While we know that jus is expressed throughout the ventral nerve cord and central brain, we have not identified the cell subpopulations that are most crucial for regulating seizure sensitivity. In this study, we investigate the importance of neurons that express both teashirt (tsh) and jus in altering seizure sensitivity. tsh is primarily expressed in the ventral nerve cord and has some expression in the central brain. tsh-GAL4-driven expression of UAS-RNAi-jus (tsh-GAL4>RNAi-jus) resulted in both in a strong bang-sensitivity phenotype in comparison to known jus mutants, such as jusiso7.8 and jusf04904, and resulted in a cold-sensitive phenotype. Interestingly, mechanical shock resulted in a different post-recovery grooming behavior than when they were cold-shocked, suggesting a trigger of a different cellular pathway. Furthermore, late third instar larval and early metamorphosis stages appear to be key developmental stages for tsh-expressing neurons. However, despite the behavioral assays, there was poor colocalization between tsh and jus expression. Overall, tsh-GAL4 is a useful driver to better understand how jus-expressing neurons affect several different behaviors.

The Knock-Down of the FKBP5 Gene Limits the HPI-Mediated Effects of the *Danio rerio* Slow Stress Response

Gursajan Gill

The FK506-binding protein 51 (FKBP5) regulates the binding of glucocorticoids to the glucocorticoid receptor (GR) in the hypothalamic-pituitary-adrenal (HPA) axis mediated stress response. A de-methylated polymorphism of the FKBP5 gene has been associated with an abnormal stress response in humans, leading to an increased risk for common stress and mood disorders such as depression and anxiety. Here, we aimed to investigate the role of FKBP5 in the zebrafish (*Danio rerio*) HPI axis mediated stress response. We used the transgenic SR4G_BH1 FKBP5 +/- zebrafish line that expressed a green fluorescent protein (GFP) downstream of several glucocorticoid response elements (GREs). This allowed us to visualize and quantify the level of stress in the zebrafish through the GFP expression in the fish. We were also able to breed embryos who could be wild type (WT), heterozygous (HET) or knock-out (KO) for FKBP5. Using a synthetic glucocorticoid, dexamethasone (DEX), we artificially induced a stress response in the offspring of the transgenic SR4G_BH1 fish. From a dose response curve, we found an effective dose of 20μg/mL of DEX. Our assay showed that FKBP5 HET and KO fish had significantly lower GFP expression than their WT counterparts, showing that a lower dose of FKBP5 reduced the stress response in the zebrafish. We also found that a Visual Background Adaptation (VBA) assay may prove to be a promising future alternative to the fluorescence plate reader for measuring the stress response in zebrafish.

Spatial and Temporal Heterogeneity of Insect Visitors to Ten Spring Ephemeral Flower Species Indicates the Flexibility and Resilience of Plant-Pollinator Networks

Alexandra Grusky

With the unprecedented decline of insect diversity across the globe and increasing environmental pressures of global climate change, the composition, stability, and persistence of plant-pollinator networks is challenged. Understanding the dynamics of plant-pollination networks is thus critical to conservation approaches for protecting pollinator species and their mutualist flower partners. Here we report the spatial and fine-scale temporal patterns of insect visitors to ten spring ephemeral flowers in Berkshire County, Massachusetts, USA: *Anemone acutiloba, Claytonia caroliniana, Erythronium americanum, Trillium erectum, Dicentra cucullaria, Dicentra canadensis, Cardamine diphylla, Mitella diphylla, Tiarella cordifolia,* and *Maianthemum canadense*. Our study is the first to document all diurnal visitors to these spring ephemeral flowers. We scored a total of 5,619 visitors from 78 distinct taxa and 10 different Orders. Our study highlights the importance of flies (*Diptera*)(3,239 visits) and native bees (*Hymenoptera*) (1,031 visits) in plant-pollination networks. Simultaneous filming of two patches of each of the species show most species overlapped, but each patch also had unique visitors even though sites were within 100m of each other. Fine scale spatial heterogeneity of visitors suggests that plants recruit local pollinators, supporting the neighborhood pollination model. Poisson analyses of one-minute intervals show visits are significantly clustered. Our study is the first to demonstrate that insects visit flowers in groups, supporting a mixed taxa foraging model, and suggesting that the benefits of cooperative foraging outweigh the costs of competition. The high insect diversity conservation of shared taxa across all flower species indicate that both flowers and insects have multiple options for foraging/pollination. This flexibility increases the resilience of the network as each responds to shifts in local abundance, the availability of their mutualist partners (pollinators or flowers), and variable weather conditions in early spring. Flexibility and resiliency are increasingly important with the threat of climate change and drivers of pollinator decline, so maintaining a diverse local visitor assemblage will increase overall network and community persistence.

Real-Time Characterization of Tachykinin-1-(Tac1)-Expressing Neuron Activity in the Parasubthalamic Nucleus Based on Food Accessibility

Kenneth Han

The motivation to eat is regulated by the relative balance of activity in appetite-inducing and appetite-suppressing neuronal populations in the brain. The parasubthalamic nucleus (PSTN) is a relatively uncharacterized region in the brain that has been implicated as a potential appetite suppression center. While studies have begun to characterize the role of the PSTN in appetite regulation, the activity dynamics of neurons in the PSTN remains largely unknown. This study characterized the real-time activity of tachykinin-1 (Tac1)-expressing neurons based on food accessibility. Specifically, we tested the following hypothesis: accessible food will cause a greater increase in PSTN activity in food-deprived mice than inaccessible food. While Tac1 PSTN neuron activity increased for both accessible and inaccessible food, there was no significant difference in the amount of PSTN neuron activity for accessible versus inaccessible food. Nevertheless, we propose that Tac1 PSTN neurons respond differentially based on food presentation.

Identification of UDP-Dependent Glycosyltransferases in Cardiac Glycoside Biosynthesis in Wallflower (*Erysimum cheiranthoides*)

Jessica Hem

Cardiac glycosides, or cardenolides, are secondary metabolites found naturally in at least twelve families of plants. Despite being used for centuries in traditional and modern medicine, the pathway by which plants synthesize cardiac glycosides remains largely unknown. Cardenolides consist of a hydroxylated steroid core with a five-membered lactone ring and one or more sugars added to the steroid. Here, we used the small, fast-growing annual *Erysimum cheiranthoides* (wormseed wallflower) as a model to identify UDP-dependent glycosyltransferases (UGTs) that add a sugar to the aglycone cardiac glycoside steroid core. Using the *Erysimum* genome and preexisting transcriptomic and metabolomic datasets, I generated a list of all of the UGTs in wallflower and then narrowed that list down to six candidate genes that we deemed most likely to glycosylate steroids. After cloning the genes and generating pure protein, I then used and untargeted LC-MS assay to determine the substrates of three of the candidate enzymes. From these assays, the data indicate that UGT 3g34 and UGT 7g34 are likely to be involved in glycosylating cardiac glycosides. If future analyses confirm these results, UGT 3g34 and UGT 7g34 would be the first UGTs identified in the cardiac glycoside biosynthetic pathway from any plant.

Evaluating the Role of the Lectin Receptor Kinase RDA2 in *A. thaliana* defenses against *A. tumefaciens*

Surabhi Iyer

Here we show that while RDA2 gene expression does not appear to be affected by *A. tumefaciens* infection, RDA2 may be involved in detecting a component of the T6SS to limit bacterial transient transformation of host plant seedlings; however, further experimentation is needed to elucidate the full extent of RDA2 involvement in transient transformation. Our results are consistent with the conclusion of Park et al. that RDA2 is not involved in the early steps of PAMP-triggered immune signaling (PTI), ruling out the possibility that it functions as a pattern recognition receptor (PRR) in plant defenses. Further studies will be needed to determine whether RDA2 does have a MAPK-dependent effect on ABA signaling in response to *A. tumefaciens* infections.

The Role of ASAP1 in Ovarian Cancer Invasion and Proliferation

Katya Khalizeva

Expression of ASAP1, a known regulator of cytoskeletal reorganization necessary for cell motility, is upregulated in 30.7% of ovarian cancers. Overexpression of ASAP1 is associated with increased cell invasiveness and is predictive of poor patient prognosis, thus positioning ASAP1 as an oncogene. Previous work in this laboratory has demonstrated that ASAP1 inhibits ovarian cancer cell growth, contrary to its expected oncogenic role. In the present study we investigated how ASAP1 may regulate invasion and growth of ovarian cancer cells. Specifically, we tested the "go-or-grow" model, according to which invasion and cell division are mutually exclusive cellular processes, in ovarian cancer cells. Thus, we hypothesized that (1) cell cycle arrest is required for invasion, and (2) ASAP1 regulates the switch between proliferative and invasive behaviors. In addition, we performed a hypothesis-generating RNA sequencing experiment in order to identify possible pathways that may mediate the effect of ASAP1 on motility and growth in ovarian cancer. First, we found that in ovarian cancer cells lovastatin-induced G1 arrest does not promote 2.5D invasion in OVC3 cells and inhibits spheroid invasion in OVC5 cells. Second, we found that ASAP1 knockdown does not affect the distribution of cells among the stages of the cell cycle, indicating that ASAP1 does not induce cell cycle arrest. Third, we identified cytokine, PI3K-Akt and Hippo pathways as differentially expressed in control and ASAP1 knockdown cells, positioning them as candidate pathways for mediating the effect of ASAP1 on ovarian cancer growth. Taken together, our findings suggest that the "go-or-grow" hypothesis does not apply to ovarian cancer, and that the effect of ASAP1 on growth is likely due to its regulation of cell survival rather than proliferation.

A soil and microbial characterization of two sites in Hopkins Memorial Forest

Isabel Lane

The soil environment is highly complex in terms of the interactions occurring between abiotic factors, soil microbes, fungi, and plant communities. This project examines two sites of differing elevations in Hopkins Forest and aims to characterize them in terms of physical characteristics, enzyme activity, and microbial communities. The sites differed significantly in average wind speed, pH, and soil carbon and nitrogen. Acid phosphatase activity was significantly different between the two sites, was negatively associated with pH, and was positively associated with soil carbon and soil moisture, indicating that these factors all play important roles in regulating phosphate availability in soil. N-acteyl-glucosaminidase activity was also positively associated with soil moisture. This information is useful in forming a baseline picture of how soil characteristics affect processes occurring within their communities. This information will prove essential as soil environments change over time due to climate change. Prep work was also complete during this study that will allow for future characterization of the microbial community, allowing for more in depth understanding of the soil microbiome

An investigation of biochemical pathways by which 17β-estradiol induces heart valve abnormalities in zebrafish

Elida Lopez

Treatment with 17β-estradiol (Est) leads to heart valve abnormalities in zebrafish (*Danio rerio*). Two pathways estradiol may work through to cause these abnormalities are the nuclear estrogen receptor pathway and G-protein coupled estrogen receptor pathway (GPER). GPER was a good candidate due to its localization in the heart and its role in heart rate regulation. Using gper knockouts we attempted to rescue the heart valve abnormalities caused by estradiol. Gper knockouts treated with estradiol did not differ significantly in the proportion of abnormal heart valves compared to gper knockouts treated with DMSO. In addition, there was no significant difference between estradiol treated knockouts and wildtypes. This suggested that estradiol does not go through GPER to cause heart valve abnormalities. Surprisingly, Gper knockout zebrafish treated with the control DMSO had a significantly higher proportion of abnormal leaflets than the wild type DMSO control. This indicated that GPER may actually be required for the heart valve to develop normally. Additionally, we attempted to rescue the effects of estradiol with epigallocatechin (EGC) because epigallocatechin was reported to rescue the effect of BPA, a xenoestrogen with similar properties to estradiol. Estradiol induced effects were not rescued by EGC suggesting it may work by a different mechanism than BPA. Future studies should further look into the nuclear estrogen receptor pathway as well as GPER's role in heart valve development.

Evaluating the role of fungal guild interactions in litter metabolism, soil organic matter formation, and the soil carbon response to nitrogen fertilization

Crystal Ma

It is well known that most plants have roots that help them secure the water and nutrients they need to survive, but much less discussed are the vast networks of host-dependent fungi that provide similar services to the plant in exchange for carbon (C). This belowground allocation provides a C input to the soil, promotes soil aggregate formation and contributes to soil C stabilization. In this study, a mycorrhizal ingrowth and exclusion experiment is coupled with a litter and soil organic matter (SOM) decomposition study to understand the role of arbuscular mycorrhiza (AM) and ectomycorrhiza (EM) in soil C dynamics. In particularly sandy, underdeveloped soils both mycorrhizae types did not have a large effect on soil C storage, however, mycorrhizae did increase soil aggregation and average soil particle size. These effects may be compounded over longer periods of time to yield important consequences for ecosystem C cycling and should be the focus of further research. Enzyme activity was not influenced by mycorrhizal ingrowth, but decreased in the grassland in response to N fertilization—pointing to the potential importance of AM priming in soil nutrient cycling.

ASAP1 Modulates Multiple Pathways to Regulate the Structure and Function of Invadosomes

Ben Maron

ASAP1 is a multi-domain protein which is part of the Arf GAP family. It serves many roles in the cell, including regulating Arf1 signaling and binding to many proteins involved in regulating the cytoskeleton. Overexpression of ASAP1 is associated with poor prognoses in many cancers, and we hypothesize that this may be due to its role in the regulation of invadosomes. These actin-rich structures protrude from the ventral surface in the cell and can push into and degrade the extracellular matrix (ECM), aiding in cell motility and invasion. Here we generate stable ASAP1 knockout lines of mouse embryonic fibroblasts and use them to assess the effect of ASAP1 on invadosome structure and function. Despite previously published data that shows that ASAP1 knockdown decreases the number of invadosomes in the cell, we do not observe a significant change in the number or structure of invadosomes with ASAP1 knockout. We do however see a significant increase in ECM degradation associated with invadosomes, indicating that ASAP1 may have multiple dose-dependent effects on the structures.

Exploring the Influence of a Male-like Cuticular Hydrocarbon Profile on the Fertility and Fecundity of Two Hybridizing Field Crickets

Nevyn Neal

Hydrocarbons comprise the cuticle of every insect, and are primarily responsible for desiccation resistance (waterproofing). Due to the variability of these cuticular hydrocarbons (CHCs), they have been co-opted for individual recognition and sexual signaling in the overwhelming majority of insect species. Their rapid evolution has also implicated them as an early pre-zygotic barrier, limiting hybridization and gene-flow between populations via behavioral isolation. In the present study, we studied the potential advantages of a particular female CHC profiles in two species of hybridizing field crickets: *Gryllus pennsylvanicus* and *Gryllus firmus*. Though males of both species have consistently similar CHC profiles, female CHC profiles are highly variable, with great variation even between individuals of the same species. Maroja et al., 2014 found that male mate choice in heterospecific *G. firmus* male and *G. pennsylvanicus* females pairings is mediated by female CHC profile, with males taking considerably less time to mate with females displaying typically male-like CHC profiles. We hypothesized that the females with male-like CHC profiles were more favored in heterospecific pairings because they were more fecund (produced more eggs) or fertile (laid more eggs that hatched) than non-male-like females. However, we found no significant difference in the fertility or fecundity between male-like and non-male-like females of either species after conspecific pairing. Instead, the benefit of our project was the compilation of a high-resolution dataset of ~230 individual CHC profiles that will prove useful in identifying the compounds present in the *G. firmus* and *G. pennsylvanicus* CHC profile.

The Effects of Perinatal and Adolescent Morphine Exposure on Cognition and Neurogenesis in Mice

Andrea Orozoco

In 2017, the U.S. Department of Health and Human Services declared the opioid crisis a public health emergency. Prescription opioid use during pregnancy has also increased sharply in the past 15 years (Rubenstein et al., 2018). Opioid misuse, opioid-related deaths, and Neonatal Abstinence Syndrome (NAS) are tangible consequences of the opioid epidemic. A substantial part of the nervous system's development takes place during gestation, therefore, exposure to drugs in utero during this critical period results in heightened long-term effects on brain structure and function (Ross et al., 2014; Vik et al., 2004). This study aims to bridge the gap in opioid addiction research and elucidate addiction pathways by exploring the effect of perinatal and adolescent morphine exposure on cognition and neurogenesis in the subgranular zone of the dentate gyrus within the hippocampus using a mouse model of perinatal and adolescent morphine exposure. To model perinatal exposure, pregnant dams were given either saline or morphine (10 mg/kg) injections from gestational day 0 to postnatal day (PND) 7. To mimic a single or casual encounter with the drugs during adolescence (PND 30-40), mice were given a second exposure to saline or morphine, which was administered in a single dose (20 mg/kg). We evaluated recognition memory during adolescence using a novel tactile recognition task. Biological markers of neurogenesis were evaluated using doublecortin (DCX) in adolescent mice anesthetized within 24 hours following the second morphine exposure. Overall, our findings suggest that perinatal morphine exposure delays the formation of characteristic milestones in development, perinatal and adolescent treatments with morphine do not impact locomotor activity, and that perinatal morphine exposure coupled with adolescent morphine exposure improves recognition memory.

Ocellarless (Oce): Understanding the Ocellar Complex in *Drosophila melanogaster*

Alvin Pacheco Omaña

Ocellarless (Oce) is a mutant that was first discovered in 1959 at the genesis of the field of *Drosophila* mutagenesis (Fahmy and Fahmy, 1959). Since its discovery, Oce has been associated with three key phenotypes, some which affect ocellar complex structures—reduction of ocellar bristles—a clipped wing phenotype, and a gap in the lateral (L5) wing vein. Besides this, the Oce phenotype has not been well characterized, nor mapped to a gene. All prior experiments that attempted to map Oce have consistently failed to do so. Our goal was to accomplish two things: characterize the Oce phenotype and to map the trait to its gene. We determined that among the Oce-associated traits, some are X-linked (reduced number of ocellar bristles and shortened L5 wing veins) and the clipped wing phenotype is autosomal. Through various three-point, duplication, and complementation experiments, we were able to narrow down the Oce locus position somewhere between 1.5 and 3.0 map units (m.u.) from the left end of the X chromosome, refuting all prior literature, and highlighting Notch (N) as a candidate gene. Although further experimentation is required, specifically N sequencing in Oce flies, the genetic evidence provided by our complementation test with N alleles suggest that Oce is not only an allele of N but may also reside within the Notch Abruptex (Ax) region. These findings will serve as a foundation for future experiments to (1) definitively map Oce and (2) hypothesize underlying genetic interactions that lead to the development of the ocellar complex structures.

Determining Whether Julius Seizure Protein Partners Skap, Nrv3, and ATPα-6a Affect Bang- and Cold-Sensitivity in *Drosophila melanogaster*

Juan Peticco

Seizure disorders affect over 50 million people worldwide, making them a major public health issue. The fruit fly *Drosophila melanogaster* presents a useful model for studying seizure disorders. Previous research has identified the julius seizure (jus) gene, which encodes a neuronal axon protein containing two transmembrane domains and an extracellular cysteine-rich loop. Past co-immunoprecipitation studies have also identified 26 protein partners that bind to the Jus protein, and their functional interaction with Jus have been studied. In this study, we identified a 41-residue domain in the intracellular domain of the Jus protein that is conserved amongst homologues that has a high concentration of phosphorylation sites as well as an integration point for MAPK1, suggesting that Jus could be involved in mediating extracellular signaling. Knocking down skap expression in jus-expressing neurons using RNAi increased rates of bang-sensitivity in affected flies, but not cold-sensitivity relative to controls. Knocking down expression of ATPα-6a, which encodes the protein isoform most abundantly bound to Jus in co-immunoprecipitation studies, did not result in increased rates of bang-sensitivity or cold-sensitivity. Knocking down nrv3 in jus-expressing neurons was lethal. This suggests that Skap acts with Jus to affect seizure sensitivity. In dissected late third instar larvae, co-expression of JusGFSTF and jus-GAL4>UAS-mCherry was observed in the central brain region, ventral nerve cord, optic lobe/brain junction, and antennal lobes. These tissues are likely to be critical for jus-mediated seizure phenotypes and can be the subject of directed jus-knockdown studies in the future. It also may be interesting to characterize the developmental phase in which nrv3-knockdown in jus-expressing neurons is lethal.

The Effect of Sleep on Agouti-Related Peptide (AgRP) Neuron Activity

Sarah Willwerth

To ensure survival, an animal must prioritize different competing drives depending on homeostatic need. For example, an animal must obtain an optimal amount of food and sleep, yet cannot engage in both behaviors at the same time. In mammals, food seeking behavior is regulated by agouti-related peptide (AgRP) neurons in the hypothalamus. Past research in the Carter lab has shown that AgRP activation can lead to both poorer quality and shorter duration of sleep, suggesting that AgRP neurons decrease the drive to sleep when an animal is hungry1. However, it is unknown whether the inverse is also true: whether sleep inhibits activity in AgRP neurons. This thesis tested the hypothesis that sleep decreases activity in AgRP neurons in food deprived mice. Mice were either fed ad libitum, food deprived for 24 hours, or food deprived and sleep deprived and then allowed to sleep for 2 hours. Neural activity was assessed in AgRP neurons using immunostaining for Fos, an indirect marker of neural activity. Sleep in food and sleep deprived mice eliminated Fos expression in AgRP neurons, demonstrating that sleep is able to inhibit the activation of AgRP neurons. Behaviorally, this inhibition of AgRP neurons may act to allow sleeping mice to sleep for longer and with higher quality without hunger signals keeping them awake. These results illuminate the interconnectedness of the neural circuits in the brain that control our hierarchy of needs.

EGF induces ASAP1 phosphorylation and affects the role of ASAP1 on cell migration

Manting Xu

ASAP1, an Arf GTPase activating protein, is a regulator of many actin-rich cytoskeletal structures and has been shown to be upregulated and associated with poor prognosis and metastasis in many cancers, including ovarian cancer. While much research on ASAP1 has focused on its effect on actin structures, less has been studied about the upstream regulators of ASAP1. In this study, we sought to determine the upstream regulators of ASAP1 in Ovcar3 ovarian cancer cells. Through transwell and wound healing migration assays, we discovered that epidermal growth factor (EGF) stimulated Ovcar3 migration and changed the effect of ASAP1 on cell migration. Specifically, ASAP1 knockdown inhibited wound healing in the absence of EGF but accelerated wound healing in the presence of EGF. Furthermore, EGF induced phosphorylation of ASAP1 at Y782. Using pharmacological inhibitors of Src and FAK, both non-receptor tyrosine kinases, we found that Src was at least partially responsible for EGF-induced ASAP1 phosphorylation at Y782, while FAK had no role. Taken together, these results identify EGF as an upstream regulator of ASAP1-mediated migration as well as ASAP1 phosphorylation, mediated by Src, suggesting that ASAP1 phosphorylation at Y782 may be a target for regulation of ovarian cancer cell migration in response to EGF.

Elucidating the metabolic pathways affected by SigU sigma factor activity in *Streptomyces coelicolor*

George Yacoub

The SigU ECF sigma factor of *Streptomyces coelicolor* has been implicated in the regulation of development and antibiotic biosynthesis in *S. coelicolor.* A knockout mutant of the anti-sigma factor gene rsuA, which is presumed to have unregulated SigU activity, exhibits significantly altered developmental morphology and secondary metabolite production compared to the wild-type strain. In this study, we attempted to elucidate the effects of rsuA mutation on *S. coelicolor* metabolism in order to gain a better understanding of the biosynthetic pathways affected by SigU activity. We used an untargeted metabolomics approach to study the effects of SigU overactivity on the various metabolites produced by *S. coelicolor* at 4 days growth on solid R2YE medium. We found evidence suggesting reduced levels of hopanoid production and increased levels of free N-acetylmuramic acid in the rsuA mutant, suggesting that SigU plays a role in cell envelope maintenance through regulating hopanoid biosynthesis as well as enzymes involved in cell wall degradation. This could result in decreased flux through glycolysis and increased flux through the pentose phosphate pathway as previously observed in the rsuA mutant strain, which could lead to further downstream consequences on multiple secondary metabolite biosynthetic pathways. Our results invite further investigation of the intricate relationships between primary metabolism and secondary metabolism in *S. coelicolor.* Future experiments that utilize different solvents for metabolite extraction, perform mass spectrometry analysis in negative mode, and perform metabolite extraction at earlier stages of the *S. coelicolor* life cycle will likely reveal the true breadth of pathways directly or indirectly regulated through SigU activity.

Chemistry

Bulk Fusion Studies of Sendai Virus to Liposomes and Application of a Mass Action Chemical Kinetic Model: Effects of GD1a, GQ1b and Cholesterol

Papa Freduah Ansu Anderson

In this thesis, I will present work studying factors that affect the fusion of Sendai virus to phospholipid liposomes. Sendai virus is an historically important murine virus of the paramyxovirus family, and it continues to be widely used in a variety of fields. Paramyxoviruses are enveloped, negative-sense RNA viruses which include prominent pathogens such as mumps, measles, and parainfluenza viruses. For paramyxoviruses to infect a host cell, viral surface proteins must first bind to the host cell membrane and subsequently catalyze the fusion of the viral and host cell membranes to deliver the viral genome into the cell. Certain general features of the binding and fusion process are believed to be conserved within the paramyxovirus family, though it is quite diverse. There remains ambiguity in the literature concerning the fusion mechanism(s) and intermediate states. Here I study the fusion of Sendai virus as a model system. I explore the fusion of the virus with unilamellar liposomes in bulk by fluorescence spectroscopy. I examined the effects of the viral receptors, ganglioside GD1a and GQ1b, and varying cholesterol concentration in liposomes on the amount of fusion observed between Sendai virus and the liposomes. The virus was prepared by inserting lipophilic R-18 dye into the viral membrane and fusion with the liposomes was studied via fluorescence de-quenching. Then, a mass-action chemical kinetic model was generated to fit the fluorescent data collected from the experiments to extract key parameters such as the rate of association between the liposomes and the virus, the number of fused liposomes per viral particle, and their rate of fusion. I observed that although GD1a and GQ1b are different gangliosides, they affected fusion by the same amount and that significant fusion of the virus to the liposomes is possible in the absence of these receptors. Additionally, there was significant fusion in the absence of cholesterol in our liposomes and the addition of cholesterol slightly reduced the total amount of observed fusion. We believe that cholesterol reduces the membrane fluidity of the liposomes and makes it harder for them to fuse to the virus. We have a working preliminary chemical kinetic model, but it would have to be developed to realistically capture the nuances in viral fusion data.

Organic Synthesis of Novel Compounds for the Inhibition of the SARS-CoV-2 Main Protease: A Collaborative Antiviral Drug Discovery Project with Drugs for Neglected Diseases initiative

Cody Philip Carrier

COVID-19 is a highly contagious disease caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and has resulted in an international pandemic and economic crisis following its emergence in late 2019. The Drugs for Neglected Diseases initiative (DNDi) is an international not-for-profit organization exploring novel therapeutic agents for diseases that possess limited economic incentive for pharmaceutical research, and in early 2020 they initiated the COVID Moonshot project to contribute toward the global efforts of designing an effective antiviral therapeutic for COVID-19. Having collaborated with the DNDi since 2018, Williams College was offered the opportunity to work on the COVID Moonshot project by developing methods for synthesizing and purifying a set of target compounds that were computationally estimated to demonstrate antiviral activity against SARS-CoV-2. This thesis focuses on the synthesis of two groups of compounds from the COVID Moonshot project's Work Packages A & C. Work Package A target compounds were classified as amidopyrimidines, and their synthesis was achieved through an amide coupling reaction between a pyrimidinamine and a carboxylic acid reagent. We successfully synthesized and purified three target compounds from Work Package A and packaged these molecules for testing as inhibitors against SARS-CoV-2. Work Package C target compounds were synthesized through a two-step process utilizing an aminopyridine, chloroacetyl chloride, and a piperazine compound. We successfully synthesized an intermediate for the Work Package C target and will continue to refine the methods for purifying this intermediate so that the target molecule can be produced. The work of this thesis has contributed to the DNDi's efforts in providing a treatment for COVID-19 for communities around the world.

The Mechanism of Limonene Oxidation by the Hydroxyl Radical: An Experimental and Modeling Study

Wyndom S. Chace

The formation of secondary organic aerosol (SOA) in the atmosphere has major implications for both human health and climate, yet the chemical mechanisms leading to SOA formation are poorly understood for many volatile organic compounds (VOCs). Limonene is an abundant 10-carbon VOC, produced by both biogenic and anthropogenic sources, for which the oxidation by the hydroxyl radical (OH) under high NOx conditions is poorly constrained. My thesis research attempted to elucidate the effect of NOx regime on the mechanism of OH oxidation of limonene, and the resulting SOA formation, through a combination of modeling and experimental work. The predictions of a widely-used gas phase model and an in-house partitioning model, both of which use the best existing mechanism for the reaction available (the Master Chemical Mechanism, or MCM), were compared to results from chamber experiments for the OH oxidation of limonene under low and high NOx conditions. Very little SOA was formed in experiments under high NOx conditions, consistent with the partitioning model, but the partitioning model did not correctly predict the high SOA yields for the reaction under low NOx conditions. From gas phase species collected from the high NOx chamber experiments, the presence of three species predicted to have high yields in the gas phase model were confirmed, and structures for several possible species not appearing in the MCM were tentatively proposed. Future work includes experimental confirmation of these possible species and the inclusion of additional mechanistic pathways in the partitioning model to better represent SOA formation.

Investigating Metal-Binding in Polymers Through Small Molecule Analogs

Andrei Draguicevic

Heavy metal pollution is prevalent throughout the globe and is increasing rapidly along with industrial practices. Environmental remediation is necessary to remove heavy metal ions from the environment and reduce their toxic effects on organisms throughout the ecosystem. Although many functionalized solid-structure remediation techniques exist, our group seeks to use functionalized polymers as mechanisms to encapsulate and remove heavy metal ions. These ligands often use soft base moieties, which have a high affinity for heavy metals due to their soft acid characteristics. This study aims to elucidate the binding interactions between zinc (II), cadmium (II), lead (II) and silver (I) and soft base ligands containing thiolate and thioether moieties. The goal of this study is to understand the individual ligand-metal interactions to guide the functionalization of polymer remediation agents. Synthesis of ligands L135, L143 and L137 was performed through a nucleophilic substitution reaction between primary amine precursors and isobutyryl chloride. Ligands were then complexed with zinc (II), cadmium (II), lead (II) and silver (I) and analyzed through ESI-MS, 1H-NMR and 13C NMR. Thiolate containing ligands showed promising results with zinc (II) and cadmium (II), while thioether containing ligands showed promising results with silver (I). Future work is proposed to determine the structure and selectivity of these ligands through X-ray crystallography and UV-vis spectroscopy.

The Effects of Particle Size Distribution on PCB Accumulation in Housatonic River Sediments

Abraham Eafa

Polychlorinated biphenyls (PCBs) are man-made persistent organic pollutants that were introduced to the Housatonic River ecosystem by a General Electric (GE) manufacturing plant in Pittsfield, MA. PCBs are formed by the reaction between chlorine gas and biphenyl. There are 209 different congeners of PCBs and of these congers, 12 are considered to be dioxin-like congeners. They get their name from the toxic class of compounds known as dioxins which cause a wide range of health problems in humans. Dioxin- like PCBs are dangerous because their chemical resemblance to dioxins allows them to behave similarly to dioxins in the human body. Studies have been conducted on the presence of PCBs in the Housatonic River and the surrounding ecosystem, but this particular study lays the groundwork for the examination of the relationship between PCB accumulation and the distribution of particle sizes present. We expected PCBs to accumulate where clay content was especially high. This prediction was based on the chemical and physical properties of clay particles. However, the results were inconclusive as it seemed clay content was not a very good predictor of PCB accumulation, especially when compared to sand and silt contents. It may also be the case that the assumptions going into the particle size distribution calculations need to be reexamined, in particular the soil particle density of our samples.

Investigation into the Methodology & Preparation of N-Aryl Indoles and Triarylamines via Nucleophilic Aromatic Substitution Reactions

Uriel Garcia

Nucleophilic aromatic substitution (SNAr) reactions are some of the most varied and widely used in organic synthesis. A catalytic SNAr reaction between amine nucleophiles, such as aniline and indole, and electron-deficient aryl fluorides is described herein. Our efforts focused on method development to optimize the reaction with regards to each nucleophile. Selectivity for the di- or triarylamine depends on the strength of the electron-withdrawing group (EWG) on the electrophile for aniline. 2,4-dinitrofluorobenzene generated exclusively the diarylamine. 4-nitrofluorobeneze, 4-fluorobenzonitrile and 4-fluorobenzotrifluoride generated the triarylamine exclusively. Yields for N-arylindoles decreased as electrophile EWG strength decreased for TBDMS-indole nucleophile. The reaction between TBDMS-indole and 4-nitrofluorobenzene was screened for optimal conditions. Synthesis of the silylindole precursor and the characterization of various N-arylamines via NMR, GC-MS, and IR are reported. Future work will investigate unsymmetrical triarylamine formation using aniline. Furthermore, the indole reaction will further be optimized by continued solvent, drying agent, fluoride source and silyl group screening. Once optimized, the mechanism will be studied using competition experiments.

Characterization of AgRP Neuron Activity Across the Sleep/Wake Cycle in Food-Deprived Mice

Faris Gulamali

Hunger and sleep are competing homeostatic processes. In mammals, agouti-related peptide (AgRP) neurons are both necessary and sufficient for feeding behaviors. It is unknown how sleep affects AgRP neuron activity in food-deprived mice. In this thesis, we recorded AgRP neurons with in vivo calcium imaging using fiber photometry in food-deprived mice and found sleep-state dependent changes in AgRP neuron activity. We found two distinct transition types—regular transitions that are characterized by long periods of sleep followed by long periods of wakefulness, and micro-transitions that are characterized by long periods of sleep followed by intermittent periods of wakefulness. During transitions, AgRP activity increases from NREM sleep to wake and decreases from wake to NREM sleep. Prior to a micro-transition into a wake-state from NREM sleep, AgRP neurons exhibit acute hyperactivity. REM sleep generally coincides with a spike in AgRP neural activity. These results demonstrate that AgRP neural activity is sleep state dependent.

Impacts of Functional Group Identity on SOA Yields and Kinetics

Andrew Hallward-Driemeier

Much of the uncertainty in climate and air quality modeling derives from the challenges of modeling organic aerosol, particularly the Secondary Organic Aerosol (SOA) fraction, which is formed by the oxidation of gas phase species to low-volatility products that partition into aerosol. Previous work has established that the structure of the parent compounds is key to determining the kinetics and vapor pressures of later products and therefore SOA yields. This work extends that analysis by comparing six molecules, each with a single functional group on a ten-carbon chain, under the same conditions to determine their relative SOA yields. SOA was generated from each precursor VOC in an environmental chamber via reaction with OH under low and high NOx conditions and the concentration of particles produced was measured. Experimental data is supplemented with results of kinetics modeling of first-generation aerosol products and volatility measurements for each major product. In all conditions tested, cyclodecane makes the most SOA, followed by 1-decene, 2-decanone, and decane. This is consistent with the expected yields for these compounds based on the branches in their mechanisms, vapor pressures of initial products, and likelihoods of fragmentation. Yields for 2-decanol and 2-decylnitrate have significant uncertainty due to errors in the collection of gaseous compounds.

Characterizing the Substrate Specificities of *Streptomyces avermitilis* 4'-Phosphopantetheinyl Transferases SAV2905 and SAV7361

Angel E. Ibarra

4'-Phosphopantetheinyl transferases (PPTases) are a superfamily of essential enzymes responsible for the post-translational activation of the carrier protein domains of polyketide synthases (PKS), nonribosomal peptide synthases (NRPS), and fatty acid synthases (FAS). PKS and NRPS enzymes use carrier protein domains to tether the growing secondary metabolite intermediate by using the 4'-phosphopantetheine (PPant) moiety as "swinging arm" to shuttle the intermediates between biosynthetic active sites. A functional analysis of the *Streptomyces avermitilis* genome has revealed the presence of seven putative PPTase encoding genes, more than in most *Streptomyces*. The aim of this study was to understand why *S. avermitilis* encodes several PPTases through in vitro characterization of their carrier protein substrate specificities. Here we overproduce PPTases SAV2905 and SAV7361 for the first time and test their ability to phosphopantetheinylate carrier proteins belonging to several classes. We studied Type II acyl carrier proteins SAV608 and SAV2840, Type II peptidyl carrier protein SAV3649, Type I acyl carrier proteins SAV943(11), SAV2895(16), and SAV2896(12), and Type I peptidyl carrier protein SAV845 as potential substrates for SAV2905 and SAV7361. Additionally, we tested the Type I ACPs SAV943(11), SAV2895(16), and SAV2896(12) as substrates for previously isolated PPTases SAV1748 and SAV3637. Analysis of reaction products using MALDI-TOF mass spectrometry showed that SAV2905 may be responsible for post-translationally modifying oligomycin synthase Type I acyl carrier proteins. It also appears that Sfp-FxxKESxxK type PPTases may have preferential selectivity towards Type I carrier proteins substrates.

The Fate of Forever Chemicals: Quantification of Per- and Polyfluorinated Alkylated Substances in Bennington, VT Soil Samples

Anna Jackowski

Per- and polyfluorinated alkylated substances, abbreviated as PFAS, are a large class of persistent organic pollutants (POPs). Many of these chemicals, such as perfluorooctanoic acid (PFOA) and perfluorooctanesulfonic acid (PFOS) are resistant to most forms of physical or chemical degradation and remain in the environment indefinitely. Because they are potential carcinogens and bioaccumulate, even low concentrations in soils and water are of concern. In this thesis, I examine PFAS contamination in soil samples from Bennington, Vermont, where PFOA contamination was discovered in 2016. Expanding on prior PFOA analysis, I developed and optimized our analytical method for 13 anionic PFAS using the high mass-resolution HPLC-MS-ToF instrument. I detected seven of these PFAS in Bennington soils, extracted with solid phase extraction. These are, from highest to lowest concentration, 6:2 FTS > PFBA > 4:2

FTS > PFPA > PFHxA > PFOA > PFOS. In 36 samples, I found a minimum ΣPFAS = 268 ± 54 pg/g dry soil and a maximum ΣPFAS = 1,505 ± 266 pg/g dry soil. No sample exceeds 2 ppb, and none exceed the Vermont screening level of 300 ppb in dry soils. There are no significant correlations between concentration and distance from the former ChemFab site where PFOA and related substances were used, indicating a more complex movement in the environment related to both groundwater and wind patterns.

Synthesis and Characterization of (CH_2)n Linked Azolium Salts

Chulwoo Kim

A set of N-alkyl substituted bis-(benz)imidazolium salts were synthesized as precursors to N-heterocyclic carbenes (NHCs), in a two-step sequence. The monosubstituted N-alkyl benzimidazole precursors were prepared from the alkylation of a benzimidazole with the corresponding alkyl bromide. The second step involved the disubstitution of dibromoalkanes with the N-alkylated (benz)imidazoles to generate the bis(azolium) salts as a powdery white solid in yields ranging from 31 to >99%. The synthetic route of these bis(azolium) salts had good tolerance to variations in the N-substituents, allowing for a broad variety of NHC precursors towards building a library of chelating bis(NHCs). The salts bear a range of linker lengths consisting of methylene units $(-CH_2)$n as linkers where n = 2-4. The salts were characterized by 1H NMR and IR spectroscopy, with some of the compounds characterized by ^{13}C NMR and/or CHN analysis. Seven of the salts have not been previously prepared. The goal from here is to assess the reactivity of the corresponding nickel complexes of our bis(NHCs) in cross-coupling reactions involving C-O electrophiles.

Lipid Compositional Variance and Yield in Liposomes

Ali Ladha

Liposomes are spherical model lipid membranes that are commonly used in basic research and medical applications. Liposomes can be prepared from multiple methods, such as extrusion, freeze-thaw extrusion, and sonication. These preparation methods are applied after a starting mixture of lipids in organic solvent is dried down and resuspended in a polar solvent, like water. While it is generally assumed that the final lipid composition of liposomes is the same as the lipid composition of the beginning lipid mixture, there is limited experimental data verifying this assumption. Furthermore, it is unclear whether the lipid mass of liposomes after preparation significantly differs from the lipid mass in the starting lipid mixture. Here, we examine if the yield and molar composition of liposomes differs from the 70:30 POPC:cholesterol starting composition of their initial lipid mixtures. We also investigate how the yield and composition of liposomes differs across the extrusion, freeze-thaw extrusion, and sonication preparation methods. Lipid mixture and liposome samples were prepared at the same concentrations from a starting mixture of POPC:cholesterol. An HPLC-ELSD system was used to separate and quantify the concentration of lipid components in lipid mixture and liposome samples. The yield and relative composition of liposomes was directly compared to that of the lipid mixtures for the three methods of liposome preparation. We observe that there is a substantial loss of lipid in all liposome preparation methods, which can be explained by the presence of an extrusion or lipid residue; the order of lipid loss from most to least was 1) extrusion, 2) freeze-thaw extrusion, and 3) sonication. Moreover, we observe wide heterogeneity in liposome composition across sample preparations and methods – the observed liposome composition departs from the 70:30 POPC:cholesterol starting composition of their initial lipid mixtures. These results indicate the final composition of liposomes differ from their intended composition and that the observed concentration of liposomes differs from their prepared concentration due to low lipid yields. As a result, the concentration-based and composition-based assumptions made in experimental assays that depend on liposome concentration and composition may not always be true.

Nucleophilic Aromatic Substitution Reactions Using Aniline Nucleophiles and Aryl Halides

Carolina Martinez

Di- and triarylamines have found extended use in pharmaceuticals, organic materials, solar cells and within electron transfer processes. Their wide array of applications has made their synthesis and optimization a target for development, specifically, the need for less harsh synthetic conditions. In this work, the synthesis and optimization of di- and triarylamines from coupled aryl halides and TMS-aniline is detailed. These studies reveal that the use of aryl fluorides typically results in symmetric triarylamine formation while the use of aryl chlorides results in diarylamine formation. In this investigation, we describe the use of varying reaction conditions in order to optimize the isolated product yield. Furthermore, we hope to leverage the differential reactivity between aryl chlorides and aryl fluorides to optimize a potential synthetic procedure to create unsymmetrical triarylamines.

Characterizing Substrate Specificities of *Streptomyces avermitilis* Carrier Protein Phosphodiesterases

Steve Menjivar

Streptomyces species usually have only one carrier protein phosphodiesterase, but the species *Streptomyces avermitilis* has two such phosphodiesterases, SAV1749 and SAV2904. The carrier protein substrates of these phosphodiesterases are key components of antibiotic biosynthetic enzymes, including polyketide synthases (PKS). These acyl carrier proteins (ACPs) require a post-translational phosphopantetheinylation for activity, and this modification can be hydrolyzed by carrier protein phosphodiesterases, thereby converting the holo-carrier protein to the inactive apo-carrier protein. The aim of this study was to elucidate the carrier protein substrate specificity of these phosphodiesterases in vitro. Holo-ACP domains from the avermectin and oligomycin PKS were produced, purified, and tested as substrates for SAV1749 and SAV2904. The phosphodiesterase reactions were analyzed using MALDI-TOF mass spectrometry to observe whether the apo-ACPs were formed. The phosphodiesterases SAV1749 and SAV2904 were not able to catalyze hydrolysis of the avermectin PKS holo-carrier protein SAV943 ACP11 to its apo-form. However, these phosphodiesterases were able to completely catalyze the hydrolysis of the oligomycin PKS holo-carrier proteins SAV2895 ACP 16 and SAV2896 ACP 12 to their apo-forms. These results may suggest that both phosphodiesterases SAV1749 and SAV2904 act on a specific biosynthetic pathway, possibly the oligomycin pathway. Furthermore, a time course experiment of activity of these phosphodiesterases showed that they both rapidly hydrolyzed oligomycin PKS ACPs which suggests that the phosphodiesterases have redundant functions, at least with the substrates tested to date. Taken together, the phosphodiesterases SAV1749 and SAV2904 may be functionally redundant in *Streptomyces avermitilis* and catalyze the hydrolysis of the carrier proteins domains involved in the oligomycin biosynthetic pathway in vivo.

Investigating Potential Antibiotic Properties of Cationic Polymers

Vanessa Quevedo Barrios

The need for antimicrobial peptide mimics has increased as a result of resistance to bacteria in currently available therapeutics. Antimicrobial peptides are ideal alternatives to fight against bacteria due to their method of attack. Their cationic peptide residues are attracted to the negatively charged bacterial cell membrane. In order for bacteria to become resistant to antimicrobial peptides, they would need to change their cell membrane makeup. Polymers are a great synthetic mimic of antimicrobial peptides because they can be further tuned to increase or decrease the hydrophobicity of the side chains, and charges can be added to the polymers. In this project, I prepared a versatile pre-polymer of poly(methyl salicylate acrylate) via reversible addition fragmentation chain transfer polymerization (RAFT). The poly(methyl salicylate acrylate) was synthesized with molecular weights ranging from 6100 g/mol to 9600 g/mol and degree of polymerization ranging from 28 to 45 repeat units, with a maximum of 50. The methyl salicylate acrylate leaving group was substituted with N,N-diethylethylenediamine (DEEN). DEEN carries a tertiary amine that was quaternized with an alkyl iodide to afford a cationic antimicrobial peptide mimic. In addition, diethylaminoethyl acrylate, a commercially available monomer, was polymerized and quaternized with four alkyl halides: iodomethyl, iodoethyl, iodobutane, and iodooctane. All of the prepared polymers, in addition to unquaternized samples, were assessed for antimicrobial activity against E. coli via a growth assay. The results suggest that the quaternized polymers have more antimicrobial activity than the unquaternized polymers. Furthermore, we see that an increase in the hydrophobicity in the side chain of the polymer also increased the extent of activity, retarding but not prohibiting cell growth. Future studies will include investigating quaternized polymers with multiple charges and varied alkyl chain length and varied charge density.

Towards the Total Synthesis of Enigmazole A: Investigation of C1–C6 Aldehyde Fragment Preparation through a Vinylogous Mukaiyama Aldol Reaction

Patrick Zhuang

Enigmazole A is a cytotoxic macrolide isolated from the marine sponge Cinachyrella enigmatica. It has shown powerful tumor suppression ability in the NCI screening process and has demonstrated promise in gastrointestinal stromal tumors with its c-Kit mutant cells. The Smith group at Williams College has explored the synthesis of marine macrolides over the past 20 years, specializing in the development of Evans-type aldol reactions as efficient and synthetically versatile tools. In the Smith approach to the total synthesis of enigmazole A, the Maitland-Japp reaction is envisioned to form the tetrahydropyran, a 6-membered heterocycle, in a stereoselective single-pot procedure. Herein, we outline the preliminary efforts to employ a Kobayashi syn-selective vinylogous Mukaiyama aldol reaction to construct the C1–C6 fragment of enigmazole A. Two stereocenters are to be installed during this step, with a subsequent stereoselective hydrogenation attempted to install a third, leading towards a Maitland-Japp reaction and eventual completion of the western C1–C12 fragment of enigmazole A.

Computer Science

Shard: Ad hoc, Reliable, Distributed Shell

Markus Feng

"Performing tasks that are distributed among many systems currently fail to achieve each of the goals of being reliable, easy to set up, closely resembling an existing technology, and friendly to users without distributed systems knowledge. Because distributed systems are inherently unreliable, succeeding in these goals require the system to provide an abstraction for error handling and recovery that account for the many failure cases that may arise. This thesis project defines a set of error handling semantics that is simple to use, but powerful enough to be applied to a diverse set of use cases. We demonstrate the utility of these semantics by implementing a shell-based programming language, Shard. Using this language, anyone with basic shell knowledge should be able to write and run scripts that runs over multiple machines reliably. The Shard language will greatly aid in increasing the accessibility and simplifying the process of running distributed programs in domains including systems administration and scientific computing."

A Practical Adaptive Quotient Filter

David Lee

A filter is a data structure that compactly and approximately represents a set. Traditionally, a filter cannot correct its mistakes. Recent work, however, has developed adaptive filters, which can correct their mistakes. This thesis integrates past work on performant non-adaptive filters and theoretical adaptive filters by developing a technique to make non-adaptive filters provably adaptive while maintaining good performance. Our technique uses arithmetic coding, a form of data compression, to succinctly represent information for adaptivity. We demonstrate the technique by implementing two practical adaptive filters. Theoretical analysis shows that these filters are provably adaptive, and experimental results show that they maintain high throughputs. While our presentation of the technique uses a particular quotient filter variant, our method for augmenting filters with adaptivity is broadly applicable.

A Filtering Approach for NFA Processing on GPUs

Andrew Thai

Pattern matching problems are found in many widely useful application domains such as bioinformatics and computer virus detection. These types of problems can naturally be solved using finite automata. As a result, there have been many efforts in improving the performance of automata processing applications. Some approaches use non-deterministic finite automata (NFA), which offer the possibility of processing in parallel multiple paths through the NFA on a given input symbol. Prior works have developed NFA processing engines that execute on Graphics Processing Units (GPU), which offer massive parallel processing capabilities. However, GPUs offer several challenges when processing large and sparse NFAs that are particularly common in this problem domain. These challenges include high memory latency of off-chip accesses on the GPU, which occur when accessing the NFA's data, and low utilization of the GPU's parallel compute resources. Our proposed work primarily focuses on reducing high-latency accesses. We propose an intermediate data structure that acts as a filter, informing the algorithm whether or not it needs to access the NFA's data that resides in high-latency off-chip memory. We attempt to apply various techniques in order to construct a filter small enough to fit into lower-latency memory. We develop several different variants of the filter with this objective in mind, but most fail to meet our small size requirement. In our evaluation of these filters, we find that a delicate balance exists between filter size and performance, where the best performing filters were the least compressed variants.

Time-Space Tradeoffs in Indexing Problems via Reductions to Function Inversion

Peter Zhao

We aim to improve and develop time-space tradeoffs for indexing problems, which are problems that allow for unbounded preprocessing of input and then querying in an online phase. We first describe the Fiat-Naor inversion scheme and its background, providing context on why function inversion is important. This technique provides a time-space tradeoff of TS3=N3 for inverting any function. We then propose a general reduction for reducing indexing problems to function inversion so that we can utilize the Fiat-Naor inversion scheme for solving. We also explain the scaffolding needed to properly apply Fiat-Naor as a black-box to solve any indexing problem. Afterward, we apply Fiat-Naor to indexing variants of two classic problems in fine-grained complexity, 3SUM-Indexing, and Orthogonal Vectors (OV) Indexing. We generalize the Fiat-Naor 3SUM-Indexing algorithm developed in past literature, and study the effects of random inputs and discuss a different approach to studying the structure of 3SUM. Applying Fiat-Naor to OV-Indexing gives us an algorithm that uses O(nc+1−δ/3) space and O(nδ) query time. Lastly, we apply Fiat-Naor to two string searching problems, Jumbled Indexing, and Substring Indexing, and construct the best-known algorithms for both problems as well as the first algorithms with a smooth time-space tradeoff. We also devise a different tradeoff for string problems, giving us a TS4=N4 tradeoff that allows us to use no more than o(n) extra space.

Geosciences

The Biophysical Controls on Tidal Channel Dynamics at Plum Island Estuary, Massachusetts
Michael T. Armstrong

Meandering tidal channels defined by bidirectional flows migrate across salt marsh platforms over time. However, it is not fully clear what biophysical factors might influence tidal channel migration rates and whether or not theory from fluvial meander migration can be used to understand these patterns. Through a combination of field work, aerial imagery analysis, and examination of creek bank Spartina alterniflora belowground root biomass, I evaluated tidal channel controls on migration rates for five tidal channels over a 62-year period at Plum Island Estuary in northeast Massachusetts. I determined that several key biophysical characteristics including bank slope, channel width, and Normalized Difference Vegetation Index (NDVI) impact the incidence of bank collapse, and notice key differences in belowground root biomass between two streams. Observed tidal channel migration rates for five streams in Plum Island Estuary when normalized by channel width were <0.01 channel widths/year. Our work highlights how channel width, geometry, and NDVI produce greater tidal channel migration rates further upstream within the estuary. This study provides further evidence for the theory that even though there are major differences between tidal and fluvial channels, migration rates of tidal channels, when normalized for channel width, are governed by curvature in a similar manner as fluvial rivers. We also provide new evidence for how differences in Spartina alterniflora root biomass might be a significant control on migration rates for tidal channels.

2019-20 Atlantic Storm Season and its Impacts on Boulder Movement along Western Ireland
Niku R. Darafshi

Drone photographs made into Metashape SfM models and processed with CloudCompare could be a useful way of monitoring and analyzing both small-scale movement and large-scale changes in CBD morphology. For the 2019-20 storm season, we documented, measured, and described ridge movement along all three Aran Islands to further expand our understanding of sediment dynamics of CBD. Both Metashape and CloudCompare generated their own sets of challenges related to alignment and scaling which made it difficult to analyze where CBD movement was occurring and at what scales. A long-term goal will be to continue monitoring these coasts over many years and track how their yearly incremental changes add and compound to create large morphological changes over time.

Coursework & Campus: Factors Influencing Undergraduate Students' Environmental Sustainability Beliefs, Motivations & Behaviors
Hayden N. Gillooly

Our research examines how external factors such as coursework and campus influence undergraduate students' engagement with environmental sustainability. We studied three components of sustainability: beliefs, motivations, and behaviors. Using a national dataset from the InTeGrate (Interdisciplinary Teaching about Earth for a Sustainable Future), we quantified the impact of coursework on students' environmental sustainability beliefs, motivations, and behaviors (ES-BMB). Unlike past studies of one campus, this dataset of 93 institutions is unique because trends cannot be attributed to one campus. After a course with InTeGrate materials, students reported: increased concerns about five anthropogenic global issues (beliefs), increased motivations to use their environmental knowledge after graduation (motivations), and more frequent engagement with twelve sustainable behaviors. To explore the role of co-curricular influences on students' ES-BMB over time (e.g, from first year to graduation), we categorized institutions according to whether they had a STARS rating by the Association for the Advancement of Sustainability in Higher Education. Students from STARS and Non-STARS institutions both have increased ES-BMB after taking a course with InTeGrate materials. There are no significant differences between the pre-instruction sustainability of STARS and NonSTARS first and second-year students, but pre-instruction sustainability of STARS students increases with class year, suggesting that factors beyond the classroom influence students' sustainability. Surveys of Williams College students revealed that students engage in particular sustainable behaviors more frequently on-campus than off-campus, supporting the notion that campuses can alter students' sustainability. Our research has implications for future studies examining the role of campuses on students' engagement with environmental sustainability.

Conducting an Indoor Air Quality Analysis for Tallevast, Florida: A Majority Black Community Facing Trichloroethylene Contamination

Molly F. Lohss

Environmental racism is a pertinent issue in the United States. A majority Black community called Tallevast, Florida has been gravely affected by environmental contamination caused by American Beryllium Company, a former Cold War era weapons manufacturer. Tallevast residents have experienced extensive environmental racism while dealing with trichloroethylene (TCE) and other organic solvent groundwater contamination. Notification of the contamination was delayed, and transparency continues to be an issue, as inadequate actions are being taken to ensure the health and safety of Tallevast residents. TCE is a volatile organic compound (VOC) with tendencies to exit the medium of water and enter ambient air. This raises serious concerns regarding indoor air quality. Only four residential buildings within Tallevast were tested for indoor air quality in 2004. To ensure the safety of indoor air in Tallevast, an indoor air quality analysis was orchestrated and performed on behalf of the community. The indoor air quality analysis was designed using civic science to allow residents to actively take part in the scientific process. Residents completed the entire air sensing process with researcher assistance through directions and phone calls. Results revealed the presence of three VOCs in all monitored buildings: toluene, ethylbenzene, and TCE. Toluene and ethylbenzene were found at non-concerning levels; however, TCE was found to be at a concerning level of 0.614 ± 0.098 ppb. The findings of the initial indoor air quality analysis need to be verified and analysis must continue to keep Tallevast and its residents safe.

Tephrochronology in the Aleutian Islands and Bering Sea: Assessing Tephra Correlations between Marine and Terrestrial Sediment Cores

Dayana Manrique

As part of a larger project, a study on tephrochronology in the Eastern Aleutian Islands and SE Bering Sea was done using marine and terrestrial lake sediment cores to aid with marine radiocarbon reservoir age reconstruction in the Bering Sea. A tephrochronology database is also important in this region as it can aid with understanding volcanic hazards, improve historical eruption records, and have archaeological implications for understanding past human migration. Glass shards collected from tephra layers in 3 marine cores from the Umnak Plateau and 3 lake cores from Sanak Island were analyzed for their major and trace element concentrations. Previous tephra data collected by former students Alice Chapman, Caroline White-Nockleby, and Roberta Miller between 2015 and 2017 was compiled with tephra data I worked on, with the help of other students, since 2018 to create a substantial tephra dataset. From the 6 marine and lake cores, ~75 tephra layers were identified, ~3,500 glass shards have been analyzed for their major elements, and ~1,700 glass shards have been analyzed for their trace elements to date. From this dataset, I focused on 3 tephra samples from the marine cores – 51JPC Massive Tephra 2, 55JPC Massive Tephra 2, and U1339C Massive Tephra 2 – and 2 tephra samples from the lake cores – Deep Lake T11 and Swan Lake T11. Based on the tephra compositions identified by plotting the major element data Alkali Silica (TAS) diagrams, these 5 tephras were marked as an initial tephra correlation. Individual tephra chemistry and potential tephra correlations were assessed using major element data plotted on bivariate plots. Potential tephra correlations were confirmed between the 3 Massive Tephra 2 samples in the marine cores, between the 2 T11 samples in the lake cores, and between all 5 marine Massive Tephra 2 and lake T11 samples. Future work will include further assessments of other tephra correlations and the incorporation of trace element data when fingerprinting and correlating remaining tephra samples.

Developing Digital Clast-Counting Methodology for Analysis of Boulder Beaches

Aria J. Mason

This study uses the Python-based PebbleCounts application (Purinton and Bookhagen, 2019) to implement grain-size analysis of orthorectified, geo-referenced images from the Minard boulder beach of W. Ireland. Traditional techniques measuring grain-size distributions are limited and possess significant biases; digital-clast counting methodology offers a promising alternative to analyze clast populations with greater efficiency and accuracy. PebbleCounts includes a fully automated (AIF) and semi-automated (KMS) approach for clast-counting. Over the course of this study, both the PebbleCounts AIF and KMS approaches demonstrated greater efficiency and precision in analyzing clast populations than comparative (digital-manual) methods. By conducting further study of boulder beaches under this approach, we can understand how these environments develop and evolve over longer time scales.

What Drives CO2 Changes over Glacial-Interglacial Cycles? Controls on Nutrient Utilization and the Biological Pump in the Subarctic Pacific

Alex Quizon

Atmospheric CO_2 and temperature have been observed to be lower during glacial periods globally, but the mechanisms driving these trends are not fully understood. Reconstructing nutrient utilization and intermediate water oxygenation is necessary for understanding the relationships between biological productivity, CO_2 storage capacity, and the climate system. Our research focuses on the high-nutrient low-chlorophyll (HNLC) region located within the subarctic Pacific and changes over glacial-interglacial (G/IG) cycles during the late Pleistocene. Previous studies in this region suggest that stronger stratification drives systematically higher nutrient utilization and thus higher CO_2 storage capacity during glacials due to the closure of the Bering Strait and the formation of North Pacific Intermediate Water (NPIW). With a sediment core from the edge of the HNLC region at the Bering Slope, IODP Site U1345 - the unpublished site for this study - we investigate changes in both nutrient utilization ($\delta^{15}N$) and oxygenation (bioturbation) in comparison to published records from the Bering Slope and basin. Through a regional comparison, we find that the $\delta^{15}N$ records converge towards the present, suggesting that the biological pump in the subarctic Pacific has become more efficient through time. However, using a novel subtraction method to define 'nutrient utilization' we do not find that the $\delta^{15}N$ records exhibit a G/IG pattern, suggesting that G/IG variability may be an artifact of the method reported in the literature. Furthermore, the bioturbation records appear to record brief events but not changes over G/IG timescales, and additional paleoproxy data would be required to fully reconstruct these mechanisms.

Mathematics and Statistics

Determining Optimal Outfield Shifting Strategies for Major League Baseball Teams
Cameron S. Edgar

Infield shifts have become increasingly popular and effective in the modern era of Major League Baseball. Conversely, the outfield cannot be nearly as well covered as the infield given its size relative to the number of outfielders. We propose a method for determining analogous fielding shifts in the outfield. In this thesis we use existing statistics generated by years of Major League data such as win probability to develop an algorithm that, given a game state and distribution of outfield hits, will search over possible fielding ranges, calculate the probability of transitioning to the next game state, the resultant change in win probability, and ultimately output the optimal fielding position for that scenario. Additionally, in order to make this analysis practical, we develop an equivalence relation to partition the set of all batters into equivalent classes such that the number of distinct fielding positions can be effectively implemented in real game scenarios.

Multiplicity-Free Gonality on Graphs
Max G. Everett

In this thesis we study a new graph invariant which we call multiplicity-free gonality, a relative of divisorial gonality where we are restricted to consideration of divisors that map the vertices of a graph G to $\{0,1\}$. We present a condition to guarantee equality between multiplicity-free gonality and divisorial gonality, as well as a proof demonstrating that divisorial gonality cannot bound multiplicity-free gonality for simple graphs. We use Dhar's Burning Algorithm to prove both of these results. We also present families of graphs with previously-known gonality and multiplicity-free gonality to demonstrate the similarities and differences between these invariants, but we present a novel proof using scramble number, a new graph invariant that acts as a lower bound to gonality.

Structures on the Space of Multiplicative Functions
Emil Graf

A multiplicative function is a function f from the positive integers to the complex numbers such that f(1)=1 and if a and b are coprime integers then f(ab) = f(a) * f(b). These functions are of great interest in number theory. Certain multiplicative functions capture important properties of the integers, and other large classes of multiplicative functions have been used to prove notable number-theoretic results. In my thesis, I consider a few of the structures that arise on the space of multiplicative functions and point to some ways that these structures might be useful, particularly in the study of mean values.

On Combinatorial Problems Related to Generalized Parking Functions
Kimberly P. Hadaway

In this thesis, we study combinatorial problems related to generalized parking functions. Our work is motivated by two different research questions posed to us by Dr. Ken Fan and Dr. Shanise Walker. First, we reframe Dr. Fan's probabilistic question in terms of defective defective parking functions, which enumerate the number of cars unable to park in the classical parking function problem, thereby providing a partial answer to his question. Second, we answer Dr. Walker's question establishing a bijection between unit interval parking functions and the Fubini rankings, which get their name as they are enumerated by the Fubini numbers.

(t,r) Broadcast Domination on Directed Graphs
Peter J. Hollander

(t,r) broadcast domination is a generalization of standard graph domination defined using the following analogy. Consider a set of cell phone towers in a graph, each with a known signal strength *t*. Each tower gives itself signal strength *t*, each neighbor of this tower receives signal strength *t-1*, each neighbor's neighbor receives signal strength *t-2,* and so on, until the signal dies out (i.e., reaches strength 0). If there are multiple towers whose signal reaches a single cell phone, those signal strengths add together. Given an integer *r*, the *(t,r)* broadcast domination number is the minimal number of towers of signal strength *t* needed to ensure that every cell phone on this graph has signal strength at least *r*. In this talk, we define the directed *(t,r)* broadcast domination number of a graph and present results related to this new graph parameter.

The Tropical Three Conics Theorem
Robin Huang

In classical algebraic geometry, the three conics theorem states given three projective conics that pass through two given points, the three lines joining the other two intersections of each pair of conics all intersect at a point. We identify and prove a tropical three conics theorem when the conics are smooth and intersections are transverse, developing a geometric classification of when five points on a conic uniquely determine it in the process. We then relax our assumptions to allow for non-smooth conics or non-transverse intersections, proving the theorem in more general cases. In particular, one of these general cases implies a tropical version of Pappus' hexagon theorem.

Potential of the Sterile Insect Technique for Control of Deer Ticks, Ixodes scapularis
Thomas G. Kirby

The deer tick, *Ixodes scapularis*, is a vector for numerous human diseases, including Lyme disease, anaplasmosis, and babesiosis. Concern is rising in the US and abroad as the population and range of this species grow and new diseases emerge. Herein I consider the potential for control of *I. scapularis* using the Sterile Insect Technique (SIT), which acts by reducing net fertility through release of sterile males. I construct a population model with density-dependent and -independent growth, migration, and an Allee effect (decline of the population when it is small), and use this model to simulate sterile tick release in both single- and multi-patch frameworks. I test two key concerns with implementing *I. scapularis* SIT: that the ticks' lengthy life course could make control take too long and that low migration might mean sterile males need thorough manual dispersal to all parts of the control area. Results suggest that *I. scapularis* SIT programs will typically take eight years, which is near the normal range, and that thorough distribution of the sterile ticks over the control area is indeed critical, necessitating aerial release and thereby increasing expense substantially. With particularly high rearing costs also expected for *I. scapularis*, the release distribution finding suggests that cost-effectiveness improvements to aerial release may be a prerequisite to *I. scapularis SIT*.

Positive Semidefinite Throttling on Directed Graphs
Benjamin N. Kitchen

A directed graph (or digraph) is a graph whose edges are ordered pairs of vertices. On a graph or digraph, a color change rule is a process by which a set of filled vertices can cause other vertices to become filled. The throttling number minimizes the sum of the size of the initial filled set and the amount of time it takes to fill every vertex. In this thesis, the positive semidefinite (PSD) color change rule is adapted to digraphs, and throttling for the PSD color change rule is studied specifically. The behavior of the PSD throttling number when the order (or direction) of an edge is changed is analyzed, and bounds for the PSD throttling number of a digraph are discussed. These bounds are later shown to be tight for trees. We then look further into what happens if the direction of every edge is changed simultaneously (the resulting digraph is called the reversal). We demonstrate that a PSD throttling process on a digraph can also be reversed to obtain a PSD throttling process on the digraph's reversal. Finally, we use this fact to study the behavior of the sum of the throttling number of a digraph and the throttling number of its reversal.

Mixed-Effect Models for Quantifying Longitudinal Gut Microbiome Volatility and Testing for Association with Health Outcomes
Daniel Jaebin Park

The human body is home to trillions of bacteria, viruses, and other microorganisms that compose communities called microbiomes, which are responsible for crucial biological functions such as regulating metabolism and immunity. Advances in sequencing technology over the past two decades have enabled the characterization of microbial communities through sequencing of the 16s rRNA marker gene and classification of sequence variants into relevant taxonomic categories, such as species or genera. Studies have shown that microbiome composition is associated with various health outcomes, from obesity to type 2 diabetes. With multiple samples from the same individual in a longitudinal study, however, we can investigate how an individual's microbiome changes over time. The volatility in microbiome composition may be more strongly associated with a health outcome than just the composition itself. In this thesis, we propose Longitudinal Microbiome Volatility Test, a method for quantifying microbiome volatility and testing for associations with health outcomes in a GLMM framework. We test the method in simulation studies and apply it to a real dataset of irritable bowel disease patients in comparison with two existing approaches.

Hopping Forcing on Graphs

John Petrucci

Zero forcing is a graph theoretic process which models the spread of information through a network. This process is dictated by repeatedly applying the standard color change rule—starting with some vertices of a graph colored blue and the rest colored white, a blue vertex *b* forces a white vertex *w* to become blue if *w* is the only white vertex adjacent to *b*. One variant of this process is the minor monotone floor of zero forcing, which lets us use both the standard color change rule and a new rule called hopping—if a blue vertex is only adjacent to blue vertices and has not yet forced, it can force any white vertex in the graph to become blue.

In this thesis, we study forcing on graphs using hopping in isolation from the standard color change rule. We begin by considering the hopping forcing number—the smallest size of an initial set of blue vertices that eventually forces the entire graph blue using hopping—and show that it is bounded by other similar forcing numbers. We then introduce the hopping throttling number of a graph, which optimizes the sum of the size of an initial set of blue vertices and the amount of time it takes for that set to force the entire graph blue. We bound the hopping throttling number of a graph from below using the graph's vertex connectivity and from above using its independence number. Next, graphs with extreme hopping throttling numbers are characterized, and the relationship between hopping throttling and throttling under other color change rules is considered. Lastly, we discuss product throttling for hopping forcing, where we optimize the product instead of the sum of the size of an initial set and how long it takes to force the entire graph, and show it behaves similarly to product throttling under the standard color change rule.

On the q-Analog of Kostant's Partition Function and the Weyl Alternation Sets of $sp_6(C)$

Maria Rodriguez Hertz

The multiplicity of a weight in a finite-dimensional irreducible representation of a Lie algebra g can be computed with Kostant's weight multiplicity formula. Similar and related to it is Kostant's weight *q*-multiplicity formula. This formula is an alternating sum over the elements of the Weyl group whose terms involve the *q*-analog of Kostant's partition function. The partition function, for some weight μ of g, is a polynomial-valued function defined as $P_q^{(\Sigma\Sigma)}$ $\Sigma= c_1q^1 + ... +$ c_n q^n where c_i is the number of ways we can write μ as a positive integral linear combination of exactly *i* positive roots. In this thesis, we give a formula for the *q*-analog of Kostant's partition function and some characterizations of the non-zero terms of the multiplicity formula for Lie algebra of type C3.

Composition of TG-Hyperbolic Virtual Knots

Alex Simons

Thurston proved that the composition of any two classical knots is a satellite knot, and thus is not hyperbolic. In this thesis, we explore the composition of virtual knots, which are an extension of classical knots that generalize the idea of knots in S^3 to knots in S×I. In particular, we prove that virtual knots behave much differently under composition: with only a few restrictions, the composition of two hyperbolic virtual knots is hyperbolic. We then prove strong lower bounds on the volume of the composition using information about the original knots.

Tipping Through Rapid Rewiring in an Epidemic Model

Kasey Stern

Infectious disease transmission through a population depends pivotally on the interactions between individuals. Motivated by the COVID-19 pandemic, this thesis investigates how changing the rate at which individuals change their connections can affect extinction of a disease. It looks at the impact of rate-induced tipping on the rewiring rate in a susceptible-infected-susceptible (SIS) epidemic model. Rate-induced tipping is a jump between states in a dynamical system caused by rapidly changing the parameters. A high rewiring rate can greatly increase the epidemic threshold and decrease the frequency or likelihood of a pandemic. I look at the impact changing the rewiring rate of linkages between nodes in my network has on the state of the disease. Applying rate-induced tipping, the speed at which the rewiring rate changes can cause a disease to jump from an endemic state to one in which the disease is no longer a pandemic and may be eliminated. Previous research (Gross et al.) studies epidemic dynamics on an adaptive network, where susceptible individuals can rewire their connections away from infected individuals. I expand their model to further investigate the impact of changing rewiring rates and the effects of rate-induced tipping. I conduct a bifurcation analysis, apply a ramping function, identify a Hopf bifurcation and limit cycles, and locate regimes where tipping can most easily occur. I uncover that the presence of these unstable periodic orbits facilitates tipping at a lower rate. My work introduces rate-induced tipping into the epidemiological sphere and provides the groundwork for future research.

An Investigation of Virus Dynamics on Starlike Graphs

Akihiro Takigawa

In the COVID-19 era, virus propagation models are of great interest. Becker, Greaves-Tunnell, Kontorovich, Miller, Ravikumar, and Shen determined the long term evolution of virus propagation behavior on a hub-and-spoke graph of one central node and n neighbors, with edges only from the neighbors to the hub (a 2-level starlike graph), under a variant of the discrete-time SIS (Suspectible Infected Suspectible) model. The behavior of this model is governed by the interactions between the infection and cure probabilities, along with the number n of 2-level nodes. They proved that for any n, there is a critical threshold relating these rates, below which the virus dies out, and above which the probabilistic dynamical system converges to a non-trivial steady state (the probability of infection for each category of node stabilizes). For a, the probability at any time step that an infected node is not cured, and b, the probability at any time step that an infected node infects its neighbors, the threshold for the virus to die out is b ≤ (1-a)/√n. This analysis was then extended to k-level starlike graphs for k \geq 3 (each k-1-level node has exactly n_k neighbors, and the only edges added are from the k-level nodes) for infection rates above and below the critical threshold of (1-a)/√n_1+n_2+\dots...+$n_{\{k-1\}}$.

In this thesis, we report on further investigations into the properties of this model on starlike graphs. In particular, we analyze the effects that changes in the number of 2-level nodes n_1 and the number of 3-level nodes n_2 have on the probabilities of infection of nodes in 3-level starlike graphs. We then report on attempts to analyze this model for generalized 3-level starlike graphs, where each 2-level node need not have exactly n_2 neighbors.

On the Representation of Low-Dimensional Signals with Periodic Activation Functions

Alexander Trevithick

We present an investigation of recent developments in the representation of low-dimensional signals, including the proposal of a novel architecture, SINONE. First, we provide background in probability and optimization with backpropagation and its convergence in the convex case. We then present a derivation of the Neural Tangent Kernel (NTK) for two-layer networks and its application for the sin activation function. From there, we introduce the recent Fourier Feature Network (FFN) and SIREN architectures for implicit representation, before presenting our own alternative, SINONE, which combines the generalization ability of FFN, with the non-saturating gradients of SIREN for more expansive applications. Finally, we show extensive experiments on these architectures and show how their NTKs differ during training.

Modeling Teacher-Student Race Match in California Public Schools

Julia J. Tucher

An important feature of classroom learning, teacher-student race match describes how students benefit from sharing a racial-ethnic background with their teachers. Understanding racial match and mismatch can help identify inequities in elementary and secondary schools. In this thesis, I construct a new data set for same-race teacher-student exposure in California public schools; define a metric to measure race match with high granularity; and explore patterns across racial-ethnic groups, school types, and student enrollment. Non-White students most frequently are instructed by no teachers from a shared demographic background. American Indian, Filipino, and Pacific Islander students observe the lowest rates of race match, while some Asian and Black students have between one and four same-race teachers each year. More students classified as Hispanic attend school with more than one same-race teacher than students in other non-White groups, with overall low rates considering their racial-ethnic majority in public schools. I conclude racial homogeneity to be statistically associated with race match across racial-ethnic groups and that trends in race match across school sector vary with the racial-ethnic group.

On Gonality-Related Graph Parameters

Benjamin L. Weber

Tropical geometry can be thought of a set of tools that allow us to associate algebraic curves with combinatorial objects such as graphs. In particular, we can model divisor theory on algebraic curves by playing chip-firing games on a finite graph. From this study, we can define a graph invariant called gonality, which is NP-hard to compute, that encodes information on how algebraic curves map to a projective line. In this thesis, we investigate two gonality-related invariants, the scramble number of a graph and a property called hyperelliptic type. First, we prove that scramble number is also NP-hard to compute, and investigate scramble numbers over cones of graphs. Then we introduce hyperelliptic type on finite graphs by providing four possible definitions and investigate which definition best models hyperelliptic type behavior observed on tropical curves.

Investigating the Role of School Homogeneity on Student Outcome Disparities in Chicago Public Elementary Schools

Katrina Wheelan

Chicago's long history of redlining led to dramatic racial and income-based residential segregation that persists today. As a result, many of Chicago's neighborhood elementary schools exhibit high levels of racial and income homogeneity. In my thesis, I link neighborhood demographics to elementary school outcomes, and I use spatio-temporal methods to investigate the relationship between school homogeneity, neighborhood income inequality, and intra-school disparities in student outcomes in 2009 and 2019. I find that income inequality has no significant association with outcome distributions, but racial homogeneity has a generally significant and positive association with the spread of student outcomes. The significance and magnitudes of these predictors changed slightly from 2009 to 2019, potentially as a result of widespread school closures in 2013.

COVID and the American Prison Industrial Complex: The Mathematical and Humanitarian Advantages of Decarceration

Nehemiah J. Wilson

The coronavirus pandemic has fundamentally changed our lives in the past 18 months. Shortly after the virus was introduced to the United States, the number of cases in the country began skyrocketing quickly. The first confirmed case of the Coronavirus in the United States was reported on January 20th of 2020, with the first death being reported on February 29th. Because COVID-19 is transmitted via aerosolized nasal droplets, those unable to socially distance and wear masks have been the most susceptible to becoming ill from the respiratory virus. Therefore, the way in which we in the United States incarcerate our citizens, and the rate at which we incarcerate our citizens, has made America's prisons and jails the perfect hunting grounds for this novel virus. The purpose of this thesis is to use an SEIR compartmental model to explore how the COVID-19 pandemic has worsened an already ghastly and inhumane prison industrial complex. To do this, we simulate a coronavirus outbreak in a local or county jail in the United States, and then simulate the implementation of certain management strategies the CDC has recommended prisons and jails implement. We then compare the effectiveness of these strategies at reducing the Reproductive Number of the outbreak with the effectiveness of doing so via decarceration (i.e. reducing the population size in the jail).

Spatiotemporal Patterns in Urban Violent Crime

Tarun Yadav

Urban crime, as understood in modern criminology is a sociological, and further a sociogenic phenomenon governed by complex, dynamic processes. Characteristics of the civic, social, and urban environment influence where and when crime events occur; however, past studies often analyze cross-sectional data for one spatial scale and do not account for the processes and place-based policies that influence crime across multiple scales. This thesis builds upon a curated dataset for studying reported crime incidents in context over the last 10 years in the City of Chicago, and (i) applies a Bayesian cross-classified multilevel modelling approach to examine the spatiotemporal patterning of violent crime in the city; and (ii) motivates directions at the intersection of Bayesian computation and data assimilation for supplementing theoretical work in mathematical criminology with observed. We utilize a grid-based and subsequently a stochastic partial differential equations (SPDE) approach to the modelling of violent crime incidents as Gaussian spatial processes and elucidate the computational infrastructure that enables sparse approximations to solution Gaussian fields of the said SPDE such that Bayesian inference is computationally feasible.

Physics

Exploration of Graphene – A study into its properties and creation

Ilana Albert

This thesis describes the techniques that we have developed for the preparation and characterization of ultrathin materials for use in future ultrafast electron diffraction experiments. While the work we have done this year is largely based on graphene, these processes can be generalized to other ultrathin materials of interest such as hexagonal boron nitride. We outline the preparation process and explain the steps we take to create a free-standing sample of graphene. Throughout the sample preparation process it is necessary to estimate the sample thickness so as to ensure that we are focusing on a flake of graphene that will be thin enough for our experiment. However, our method of graphene exfoliation is random and produces a wide range of graphite thicknesses that are scattered over an area too large for an atomic force microscope to be an effective measurement tool. In answer to this, we have developed a method for estimating the sample thickness while the graphite is on a silicon wafer topped by a thin layer of silicon dioxide. We have studied the systematic error that accompanies this technique, cross checked its accuracy by directly measuring sample thickness using atomic force microscopy, and determined that it is a useful tool to use in the future. This research will continue to advance our progress towards studying ultrathin materials using ultrafast electron diffraction.

Freeze-in Leptogenesis via Dark Matter Oscillations

Justin Berman

Models of freeze-in dark matter that incorporate two or more dark matter mass eigenstates, typically below 100 keV, can simultaneously account for the observed baryon asymmetry through the oscillations of the out-of-equilibrium dark matter particles. We consider the case in which the dark matter is produced by early-universe decays of electroweak-charged scalars, the lightest of which is typically in the few hundred GeV to few TeV range to realize the observed dark matter and baryon densities. Using a network of quantum kinetic equations that describe dark matter production, annihilation, and oscillations, along with Standard Model processes, we find that the minimal model, with two dark matter mass eigenstates and a single scalar, is tightly constrained once we take into account astronomical bounds on warm dark matter. Including Yukawa couplings of the scalar beyond its interaction with the dark matter or adding one or more additional scalars significantly expands the viable parameter space, much of which has the lightest scalar being long-lived at the Large Hadron Collider.

Analysis of the Quantum Adiabatic Algorithm and Quantum Approximation Optimization Algorithm

Nico Coloma-Cook

Quantum algorithms created for Noisy Intermediate Scale Quantum (NISQ) devices are the building blocks of realizable algorithms on quantum hardware that will reshape our future in the next decades. In this thesis, we attempt to construct the Quantum Approximate Optimization Algorithm (QAOA) and implement it using the TensorFlow Quantum API. We test this implementation a on a 6-node, 3-regular problem instance of the MaxCut problem, bench-marking performance using the well researched approximation ratio metric[1]. We then construct the Quantum Adiabatic Algorithm (QAA) applied to MaxCut and highlight the crucial differences between QAOA and QAA. We implement a classical machine learning optimization method for QAOA on MaxCut and discuss the growing area of machine learning techniques applied to NISQ algorithmic frameworks.

Frequency Resolved Optical Gating: Measuring the World's Smallest Ruler

Declan Daly

This thesis documents the workings, construction, and collected data of a FROG (Frequency Resolved Optical Gating) device. This device is necessary to characterize ultrafast pulsed lasers for use in an ultrafast electron diffraction experiment. FROG operates by producing a spectrogram of a laser pulse and inferring the temporal profile via a FROG inversion algorithm. FROG was constructed in our lab and data suggests reliable operation for 1550nm pulses. Unfortunately, FROG currently fails to produce convincing results for 1030nm pulses. Optimization is possible by improving phase-matching conditions and implementing FROG trace corrections for data indicative of poor phase-matching.

Codon Translation Rates Are Uniform?!

Brendan Hall

Differential codon usage has been hypothesized as a regulator of protein synthesis rates, with rare codons with lower tRNA concentrations thought to slow translation. Ribosome Profiling experiments provide a snapshot of the location of all of the ribosomes as they translate messenger RNA. By analyzing codon dwell times, we investigate the dependence on tRNA concentration. We find only a very slight correlation, indicating that the peptide transfer or translocation steps, and not tRNA accommodation, is rate limiting in translation. The statistical distribution of Ribosome Profiling counts is very wide and skewed. Genes have a few codons where ribosome occupancy is many times the mean, and many locations that are significantly below the mean. We find that a Poisson Log-Normal (PLN) is an excellent descriptor of the distribution of counts in genes. Furthermore, the PLN standard deviation parameter is nearly universal for genes with mean counts ranging across many orders of magnitude. All codons exhibit a wide range of translation speeds, from fast and slow. The cause of the speed variations is unknown, but our analysis shows speeds in replicates are correlated. Ribosomes normally translate messages with a three base (codon) periodicity. Occasionally the ribosome slips, and the frame-shifted message is translated. Often these shifts lead quickly to stop codons, but we designed synonymous sequences without out-of-frame internal stops to study protein production ending in all three reading frames. Our experiments include a gene with a known -1 frameshift, one with a known +1 frameshift, and another to test whether frameshifting is responsible for attenuated protein production. Preliminary experimental results are reported.

Optimal Control and Circuit Synthesis of Quantum Gates

Hyeongjin Kim

We consider a system of two fixed-frequency transmons that are parametrically coupled via a tunable bus. By parametrically oscillating the bus at the $|0\rangle\leftrightarrow|1\rangle$ transition frequency, we implement a two-qubit gate denoted $\sqrt{i}SWAP_{\varphi}$ with gate errors below 10^{-3} for gate times between 5ns and 60ns (with a gate error of 8.7×10^{-5} at 5ns). This is achieved by using shaped cosine pulses (a linear combination of Fourier basis functions) and tuning their parameters to minimize the leakage to the non-computational subspace. Our analytical and numerical results present a promising approach to achieving fast, high-fidelity two-qubit gates for fixed frequency transmon systems.

Time Projection Chambers: Background Simulations and Argon Purification for a Low-Mass WIMP Search

Duncan McCarthy

There is abundant indirect evidence that the universe is filled with non-baryonic dark matter. As limits on the dark matter mass and cross section get restrictive, direct detection exper- iments are increasingly interested in understanding backgrounds at lower energies. The Giovanetti lab has made progress towards simulating and analyzing background sources in a liquid argon detector in the sub GeV/c2 WIMP dark matter regime. Using GEANT4 and the ROOT data analysis framework, we have successfully demonstrated a detector response reconstruction algorithm along with three analysis algorithms for reducing background events: a multi-scatter cut, primarily targeting high energy gammas; a fiducialization cut, targeting alpha and beta particles; and an active veto cut targeted at neutrons. Our work provides the foundation for higher statistics simulations with an array of background particles that will be used to optimize detector geometry and material choices.

In parallel, we have begun fabricating an argon purification and condensation loop that will be used for research and development of dual-phase argon time projection chamber detectors. We have demonstrated a feedback control system that will precisely control the pressure inside the detector chamber by controlling the condensation rate of gaseous argon. Along with designing and building a frame, gas manifold, and science chamber feedthroughs, we have machined a small, single-phase argon detector that will house two sensitive silicon photomultipliers. In the near future, we hope to verify the system by measuring signal response as a function of argon purity as the concentration of impurities are reduced over time.

Transition Polarizability and Amplitude Measurement of the Lead $6p^2\,^3P_0$ $6p7s\,^3P_0$ Transition Using Faraday Rotation and Absorption Spectroscopy

Gabriel Patonette

We have made progress towards precisely measuring the $(6s^2)$ $6p^2\ ^3P_1$ $6p\ 7s\ ^3P_0$ electric dipole (E1) scalar polarizability using Faraday rotation spectroscopy with resolution below 1 microradian in a transverse atomic beam spectroscopy arrangement. Our improved furnace generates a beam of lead atoms, which we detect with a crystal oscillator circuit. Now that we can produce a beam, we are in position to detect the optical rotation of the M1 laser to calibrate our apparatus. To prepare for the two-step excitation of the atoms using the pump M1 and probe E1 lasers needed to measure the E1 polarizability, we have locked the M1 laser to a Fabry-Pérot peak which has reduced its frequency instability to the 100 kHz level. In a separate experimental effort, we have made a preliminary measurement of the E1 transition amplitude using direct absorption spectroscopy of the E1 and M1 lasers in a large commercial furnace that houses an isotopically pure Pb 208 quartz cell. By comparing the absorptivity of the two transitions and accounting for the Boltzmann factor reduced thermal population of the E1 ground state, we demonstrate the feasibility of a 1% accurate determination of the E1 transition matrix element. We propose several improvements that would allow us to measure the temperature to within 1°C, which is required for achieving this desired accuracy.

Linnik Interference Microscopy for Measuring High-Speed Dynamic Mechanics

Nicholas Patino

High-speed, three-dimensional measurements of sub-micron-scale dynamics in soft materials are challenging to obtain with conventional optical techniques due to their rapid topographical evolution. These dynamics are particularly relevant in soft matter systems undergoing adhesive contact where the governing mechanics do not subscribe to a classical continuum model, but rather a complex interplay of strain, adhesion energy, elastomeric

network structure, and dissipation mechanisms. Understanding which mechanisms dominate at small length and time scales provides information that fits the larger narrative of a sequence of self-driven dynamics following a nascent adhesive contact: an active area of research in The Jensen Lab. It is also clear that vibrational dynamics of thin soft matter systems operate on comparably small temporal (frequency) and length scales, making their

measurements just as challenging. Being able to measure the vibrational modes of small, thin, soft matter systems would create an easily parameterizable model for elastodynamic wave propagation in larger systems such as biomedical prosthetic tympanic membranes, and percussive membranophones. These systems are conveniently also examples of materials subject to adhesive contact dynamics. The prevalent nature of high-speed sub-micron-scale dynamics in adhesive soft matter systems therefore warrants the demand for a non-invasive apparatus that can capture quick, small, three-dimensional deformation. In this thesis, we discuss our Linnik interference microscope: a high-speed 3D imaging apparatus developed in The Jensen Lab.

Towards the Measurement of the $6s^2\ 6p^2\,^3P_0\rightarrow 6s^2\ 6p^2\,^1D_2$ Forbidden E2 Transitions in Lead via Faraday Rotation Spectroscopy Using a Heat Pipe Oven

Patrick Postec

We have made progress towards more precise measurement of the $6s^2\ 6p^2\,^3P_0\rightarrow 6s^2\ 6p^2\,^3P_2$ electric quadrupole (E2) transition in lead, which will hopefully allow us to soon detect the $6s^2\ 6p^2\,^3P_0\rightarrow 6s^2\ 6p^2\,^1D_2$ (E2) transition. To observe either transition, we use Faraday rotation spectroscopy in a heat pipe. While the former has been measured many times before in the lab, the latter has never to this day as it is extremely weak (approximately 200 times weaker than the former). Consequently, we have had to significantly reconfigure our apparatus from what we were using to improve the sensitivity of our setup. We have replaced the small quartz cell with a much longer ceramic heat pipe, expanded the heating system to extend the interaction length and increase maximum temperatures, and built a large solenoid to provide a stronger magnetic field and over a longer range. Additionally, we have out of necessity shifted our interest away from pure lead samples and are instead using a natural abundance one. The resultant spectrum is much more complicated, and we have done considerable theory work to account for these effects. Finally, we have just begun to observe the $6s^2\ 6p^2\,^3P_0\rightarrow 6s^2\ 6p^2\,^3P_2$ transition signal in our new and improved experimental setup, and we present the preliminary results. They are rather promising and indicate that we can plausibly measure the $6s^2\ 6p^2\,^3P_0\rightarrow 6s^2\ 6p^2\,^1D_2$ transition in the near future.

Mode-locked Fiber Lasers for Ultrafast Electron Diffraction Experiments
Joshua Reynolds

This thesis documents the design and construction of two pulsed fiber lasers that could be used in ultrafast electron diffraction experiments. A mode-locked stretched-pulse fiber oscillator using erbium-doped fiber produces approximately 100 pJ pulses with transform-limited pulse durations of less than 100 fs at a repetition rate of 35.0 MHz. Preliminary pulse characterizations in the time-domain are enabled by a recently assembled frequency-resolved optical gating setup, and we predict that positively chirped pulses are coupled out of the cavity with durations of about 920 fs. We also present the simulation and construction of a dissipative soliton fiber oscillator made with ytterbium-doped fiber. We demonstrate mode-locking at a repetition rate 42.7 MHz and measure pulses with 3.5 nJ pulse energies and transform-limited pulse durations of 180 fs. The pulses are expected to be positively chirped and to have durations on the order of a few ps. Finally, we present the design and simulation of a fiber laser amplifier that can be seeded by the dissipative soliton oscillator for the production of 2 μJ pulses that are compressible to sub-200 fs durations for future pump-probe electron diffraction experiments.

A New Ion Trapping System To Study Mesoscopic Heat Transfer
Paige Robichaud

The Doret Lab has installed the High Optical Access (HOA) 2.1 ion trap from Sandia Laboratories to ultimately support heat transport measurements in chains of trapped Ca^+ ions. The process to fully incorporate the HOA trap into the lab has involved the construction of several supporting elements crucial to its functionality. The home-built in-vacuum wiring assembly successfully establishes an electrical connection between the HOA trap's electrodes and vacuum flange feedthrough using a zero-insertion-force socket. The vacuum chamber also houses calcium-filled ovens, a loading mask to block unwanted calcium flux, and a ground screen to shield the ion from charged surfaces in the chamber. External to the chamber we assembled home-built helical resonator to amplify the RF signal, Helmholtz coils to generate a magnetic field, and optical paths to direct lasers to address a trapped ion chain. The apparatus is now ready for our first attempts to trap Ca^+ ions, and down the road will allow us to study mesoscopic heat transfer.

Towards the Precise Measurement of Isotope Shifts in Transitions of non s-state Electrons
Matthew Roychowdhury

Precision isotope shift measurements have the potential to place bounds on possible char- acterizations of physics beyond the Standard Model, and also provide valuable data for comparison with atomic and nuclear theory. Our research endeavors to place bounds on the Standard Model by investigating the linearity of King Plots, the construction of which requires the trapping of four different spin-zero ionized isotopes of the same element and the comparison of the energy of the same transition on each of the four isotopes.

In this undertaking, we have begun the development of new equipment and exploration of techniques heretofore unused by the lab that will allow future researchers to undertake more precise measurements of isotope shifts than have been accomplished with the lab's existing toolset. We have designed a new 3-dimensional Paul Trap that can generate potential wells orders of magnitude deeper than those provided by the 2-D Paul Traps currently in use. This design is currently under construction, and will allow for longer ion trapping lifetimes. In addition, we designed and constructed a new optical lens for use in fluorescence detection in the 3-dimensional Paul Trap.

Apart from developing new hardware, we have searched for a new ion for use in isotope shift measurements that, unlike the ion currently in use, Ca^+, features accessible transitions not involving electrons in s-orbitals; the absence of these transitions may allow us to place sharper bounds on physics beyond the Standard Model. Lastly, we explored the use of the quantum logic spectroscopy and two-state entanglement; the first technique allows for easier state preparation, detection, and cooling of the new species of ion, while the latter technique may offer us the ability to make isotope shift measurements with many orders of magnitude greater precision than previous measurement techniques used in the lab.

Computational and Experimental Efforts to Develop a Dual-Phase Argon Time Projection Chamber Detector Optimized to Search for Low-Mass Dark Matter

Declan Smith

Roughly 25% of the mass-energy density in the Universe is unaccounted for and can be explained by the existence of dark matter. Decades of experiments have set upper limits on dark matter mass and dark-matter-baryon cross section but there are large portions of unexplored parameter space, especially at lower dark matter masses. This thesis reports progress towards the development of a novel, dual-phase argon time projection chamber (TPC) optimized to search for low-mass dark matter. Simulations are being developed to conduct optimization and sensitivity studies of a proposed TPC design. A custom Geant4 framework was used to simulate particle interactions in the detector geometry and ROOT was used to analyze the data. The interactions were clustered to fold in the detector's imperfect temporal and spatial resolution, and the clusters were subject to three data cuts designed to remove background signals but keep the signals made by dark matter. These algorithms were validated and optimized for use in full-scale, high-statistics simulation runs.

This thesis also describes the design and construction of an argon purification system. The system, which consists of an argon dewar, a recirculation pump, a chemical purifier ("getter"), an argon condenser, and a vacuum pump, will be used to carry out critical calibration measurements and tests for the development of the TPC. The system is entirely self-contained on a 102"×60"×50" aluminum stand. Also on the stand is a purposely designed data acquisition system. A preliminary validation measurement of light detected by a custom silicon photomultiplier in a thermos of liquid nitrogen was made with the new DAQ system. Analysis of the data reveals the successful resolution of single-photon signals with the DAQ.

Psychology

Discerning Durability: Factors Predicting Durable and Non-Durable Revision of Implicit Impressions
Sarah Baldree

Previous research has provided conflicting evidence about whether or not implicit evaluations can be changed durably. Even if an intervention may appear to be effective immediately after occurring, these effects may no longer be evident even hours later (Lai et al., 2016). However, recent work in our lab has shown that exposure to a single piece of highly diagnostic information can cause implicit updating that is both immediate and durable (Cone, Flaharty, Abstract Ferguson, 2021). Thus, the main goal of this thesis is to understand the predictors of durable vs. non-durable implicit revision and isolate factors that cause one pattern of revision over the other. In 3 studies, we demonstrate both types of implicit revision within a single paradigm using the same familiar target. Further, Study 3 indicates that the hypotheticality of evidence presented has implications for the durability of implicit change. Implications for theories of implicit cognition are discussed.

Anti-Gay Prejudice: The Influence of Social Norms and a Self-Affirmation Framework
Matan Levine-Janach

Previous literature has suggested that group norms have a powerful influence on expressions of anti-gay prejudice, but there is little research on the role of such norms in online contexts or across the political spectrum. The current research offers a novel intervention for increasing approval of gay rights legislation among conservatives whereby individuals are exposed to an ambiguous norm about gay rights through anonymous commenters. In particular, participants were exposed to mixed attitudes, some of which were prejudiced and some of which reframed gay rights as an issue that aligns with conservative values. Study 1 (N = 369) found that participants exposed to a prejudiced norm expressed greater agreement with a discriminatory decision from an adoption agency than those exposed to an anti-prejudice norm. Study 2 (N = 420) revealed that conservatives exposed to the ambiguous norm intervention indicated significantly greater approval of a law ensuring that gay couples have an equal opportunity to adopt than did conservatives exposed to a strong norm or no norm. Study 3 (N = 286) offered a pre-registered replication of the results found in Study 2 on a workplace discrimination law. Study 4 (N = 315) indicated that self-affirmation eliminates the effect of the ambiguous norm on levels of approval of the workplace discrimination law, suggesting that the two interventions should be used separately. These studies suggest that an ambiguous norm may serve as a robust intervention for reducing anti-gay bias in online contexts. Limitations of the current study as well as potential future applications are discussed.

Using Novelty-Facilitated Extinction to Ameliorate Maladaptive Fear
Gwyneth Maloy

Exposure therapy is a common treatment for anxiety-related disorders; however, many individuals are unresponsive to this treatment and/or prone to relapse over time. Exposure therapy involves the systematic confrontation of fearful stimuli in a controlled setting; this process is modeled in rodents using a technique called extinction training. In this project we use three mouse strains with distinct genetic backgrounds to evaluate the role of genetic factors on extinction learning and recall. We found that DBA/2J mice show significantly faster and more robust fear extinction than 129S1/SvImJ and C57BL/6 mice, which do not differ significantly from each other. Further, we evaluated the effects of a new extinction learning paradigm, called novelty-facilitated extinction (NFE), on fear extinction learning and recall relative to traditional single-context fear extinction (SC-FE) paradigms. While mice in both groups showed significant within-session and between-session extinction, our data suggest that NFE mice showed larger reductions in freezing over the three days of extinction training. Finally, we conducted a proof-of-principle experiment in which we used cfos immunostaining to identify hippocampal engram cells that were active during extinction recall. By validating this experimental pipeline, the current project paves the way for future experiments interrogating the relationship between genetic background, neural activation, and behavior during extinction recall.

The Effects of Perinatal Opioid Exposure on Adolescent Locomotor Sensitization

Simone Veale

The rate of opioid use among pregnant women in the United States has increased drastically over the past years. However, research on the long-term neurobehavioral consequences associated with early opioid exposure in humans has been limited. The goal of the present study was to determine how early exposure to opioids mediates sensitivity to drugs of abuse later in life. To achieve this, we utilized a 2 (Perinatal exposure: saline vs. morphine) x 3 (Adolescent exposure: saline, methylphenidate, oxycodone) experimental design. Perinatal exposure began on gestational day (GD) 0 and continued up until postnatal day (PND) 7, which captures the equivalent of a full three trimester human pregnancy. Drug sensitivity was assessed in adolescence using the locomotor sensitization paradigm, in which animals are assessed for augmented locomotor activity following repeated exposure to a consistent dose of a psychoactive drug. We found that perinatal morphine exposure delayed expression of developmental milestones but did not significantly alter pup weight compared to saline controls. When tested in adolescence, morphine-exposed animals displayed locomotor sensitization to oxycodone but not methylphenidate, suggesting that that perinatal morphine exposure induces drug-specific effects on locomotor sensitization in adolescence. These data highlight the importance of investigating the long-term effects of early opioid exposure in order to decrease the incidence of opioid epidemic on future generations.

Can Romantic Relationships Span the Political Divide? Estimates of Political Similarity Among Members of Couples

Allie Weiner

There is an abundant amount of research in the field of psychology refuting the “opposites attract” notion (Berscheid Abstract Reis 1998). Specifically, politics play a huge role in today’s world, and would seem like an important aspect of life to agree with your partner on. Yet, there are politically mismatched couples who survive this divide. How do they do this? The current research makes four main predictions: that politically similar couples will be more common than dissimilar couples, that people in relationships will overestimate their similarity to their partner, that dissimilar couples will tend to avoid talking about politics, and that these two mechanisms should be related to overall closeness. Two studies were conducted to examine how accurately couples know each other, how similar they actually are to each other, and how similar they think they are based on their political views. Results indicate that politically matched partners are more common than unmatched partners, that couples do overestimate their similarity, regardless of how similar they are in reality, and that politically opposite couples tend to avoid talking about politics. There was no evidence that either of these mechanisms were directly related to overall closeness. An interesting paradox emerged in the findings due to the little variability on the closeness scale responses.

PUBLICATIONS

Astronomy

Haze in Pluto's atmosphere: Results from SOFIA and ground-based observations of the 2015 June 29 Pluto occultation

Jay M. Pasachoff, Bryce A. Babcock, Edward W. Dunham, Ian S. McLean, Jürgen Wolf, Fumio Abe, Eric E. Becklin, Thomas A. Bida, Len P. Bright, Tim Brothers, Grant Christie, Peter L. Collins, *Rebecca F. Durst '17*, Alan C. Gilmore, Ryan T. Hamilton, Hugh C. Harris, Chris Johnson, Pamela M. Kilmartin, Molly Kosiarek, Karina Leppik, Sarah E. Logsdon, Robert Lucas, Shevill Mathers, C. J. K. Morley, Peter Nelson, Haydn Ngan, Enrico Pfüller, Tim Natusch, Hans-Peter Röser, Stephanie Sallum, Maureen L. Savage, *Christina H. Seeger '16*, Ho Chit Siu, Chris Stockdale, Daisuke Suzuki, Thanawuth Thanathibodee, Trudy Tilleman, Paul J. Tristram, Jeffrey Van Cleve, Carolle Varughese, Luke W. Weisenbach, Elizabeth Widen, Manuel Wiedemann

Icarus, 2021, 356, 1 March 2021

On UT 29 June 2015, the occultation by Pluto of a bright star (r′ = 11.9) was observed from the Stratospheric Observatory for Infrared Astronomy (SOFIA) and several ground-based stations in New Zealand and Australia. Pre-event astrometry allowed for an in-flight update to the SOFIA team with the result that SOFIA was deep within the central flash zone (~22 km from center). Analysis of the combined data leads to the result that Pluto's middle atmosphere is essentially unchanged from 2011 and 2013 (Person et al. 2013; Bosh et al. 2015); there has been no significant expansion or contraction of the atmosphere. Additionally, our multi-wavelength observations allow us to conclude that a haze component in the atmosphere is required to reproduce the light curves obtained. This haze scenario has implications for understanding the photochemistry of Pluto's atmosphere.

Anomalies and fluctuations of near-surface air temperature at Tianhuangping (Zhejiang), China, produced by the longest total solar eclipse of the 21st century under cloudy skies

Peñaloza-Murillo, Marcos A., Michael T. Roman, and Jay M. Pasachoff

PASP-101036.R1, 132 114503, 2020

During a total eclipse of the Sun, the solar disk blocked by the lunar disk produces an instant and strong decline of energy at the surface. This loss of energy leads to decreasing air temperatures near the surface. Anyone under a completely clear sky, with a total solar eclipse (TSE) in progress, feels a cooling, whose minimum is reached a few minutes after totality. This drop in temperature is known as an anomaly and this delay is called thermal lag. During a TSE air temperature changes appreciably not only in magnitude but also in timing, depending on weather and geographical conditions. If the eclipse is partially or totally obscured by clouds, some effects are produced on the thermal lag. Under clear skies, the temperature response lags behind the change in solar flux as one expects in TSE; however, under cloudy skies, the lag can reverse in early and/or late stages of partial phases. The normal heating of the surface by the Sun, which drives turbulent motion in the air layer near the surface, is disrupted during the eclipse. The 2009 TSE in China provided an opportunity to have a look at these kinds of perturbations caused by this eclipse. In this paper, the second of a series of three, we analyze the near-surface air temperature response, at three different heights over the ground, recorded by the Williams College expedition under meteorological conditions characterized by cloudy skies during the longest total solar eclipse of the 21st century on 2009 July 22, at Tianhuangping (Zhejiang), China. An analysis of the relationship between solar radiation and air temperature was made by applying a study previously published in the first paper of this series in which we evaluated the cloudiness contribution in estimating the impact on global solar radiation throughout this phenomenon at that site. The analysis of this response includes linear and absolute negative anomalies as well as fluctuations, which was undertaken through a statistical study to get information on the convection activity produced by the latter. The fluctuations generated by turbulence were studied by analyzing variance and residuals. The results, indicating a steady decrease and recovery of both perturbations, were consistent with those published by other studies for this total solar eclipse.

An empirical study of near-surface air temperature lag and delay function during the longest total solar eclipse of the 21st century at Tianhuangping (Zhejiang), China, under cloudy conditions

Peñaloza-Murillo, Marcos A., Michael T. Roman, and Jay M. Pasachoff

Publications of the Astronomical Society of the Pacific, May 2021, submitted

Among the different ways that the solar light can be interrupted, the most impressive is by a solar eclipse. Solar radiation, respond instantaneously, but others, such as the near-surface air temperature, respond gradually. This variable reacts to the steadily switching off of the Sun's radiation by the Moon by diminishing its value until it reaches a minimum. This process, under clear skies, occurs later than the instantaneous response of the solar radiation; therefore, the response of the terrestrial temperature is not instantaneous: there is a lag. Sometimes, when clouds are present, this lag reverses, as occurred during the cloudy and longest total solar eclipse of this century in China. Although during a solar eclipse changes in near-surface air temperature typically lags behind changes in solar radiation, observations sometimes show that under cloudy skies an unanticipated cooling prior to totality is noted such that the atmospheric lag disappears leading to an unexpected pre-minimum effect. That was the case found during the longest total solar eclipse of the 21st century, which we observed from Tianhuangping (Zhejiang) on 22 July 2009. We attempt to analyze mathematically this opposite lag through a (tentative) "delay function," derived using our own measurements from this eclipse at three different heights above the ground. We describe how this lag changes with time. We use two methods: (1) the solar radiation - instantaneous temperature method takes the solar radiation model and the obscuration function into account; (2) the geometrical occultation function method, which only uses the occultation function used by others. Results show that under cloudy skies the first performs better than the second. The delay function has been applied to derive the delayed empirical near-surface air temperature profile that would have been the case in a hypothetical clear sky. Results also show that the fall in air temperature would have instrumentally been imperceptible or undetectable over heights of 15 m above the ground approximately.

Early Results from the Solar-Minimum 2019 Total Solar Eclipse

Pasachoff, Jay M., Christian A. Lockwood, John L. Inoue, Erin N. Meadors, Aristeidis Voulgaris, David Sliski, Alan Sliski, Kevin P. Reardon, Daniel B. Seaton, Ronald M. Caplan, Cooper Downs, Jon A. Linker, Glenn Schneider, Patricio Rojo, and Alphonse C. Sterling

IAU Symposium 354, Solar and Stellar Magnetic Fields: Origins and Manifestations, Copiapo, Chile, July 2019, pp. 3-14 (Cambridge University Press), 2019

We observed the 2 July 2019 total solar eclipse with a variety of imaging and spectroscopic instruments recording from three sites in mainland Chile: on the centerline at La Higuera, from the Cerro Tololo Inter-American Observatory, and from La Serena, as well as from a chartered flight at peak totality in mid-Pacific. Our spectroscopy monitored Fe X, Fe XIV, and Ar X lines, and we imaged Ar X with a Lyot filter adjusted from its original H-alpha bandpass. Our composite imaging has been compared with predictions based on modeling using magnetic-field measurements from the pre-eclipse month. Our time-differenced sites will be used to measure motions in coronal streamers. Keywords. Sun: corona, eclipses, instrumentation: spectrographs.

Air temperature and humidity during the solar eclipses of 26 December 2019 and of 21 June 2020 in Saudi Arabia and in other eclipses with similar environments

Peñaloza-Murillo, Marcos A., Abouazza Elmhamdi, Jay M. Pasachoff, Michael T. Roman, Yu Liu, Z. A. Al-Mostafa, A. H. Maghrabi, H. A. Al-Trabulsy

http://arxiv.org/abs/2011.11460

We report air temperature and humidity changes during the two solar eclipses of 26 December 2019, and of 21 June 2020, respectively, in the cities of Al-Hofuf and Riyadh in Saudi Arabia. During the December eclipse the Sun rose already eclipsed (91.53% of the area covered) while the June eclipse, although also annular in other places of the Arabian Peninsula, was just partial at Riyadh (area covered 72.80%). This difference apparently affected the observed response on the recorded variables of temperature, relative humidity (RH) and vapor pressure (VP) in the two events. Change in these variables went unnoticed for the first eclipse since it was within the natural variability of the day; yet for the other, they showed clearly some trend alterations, which we analyze and discuss. A decrease in temperature of 3.2 °C was detected in Riyadh; however, RH and VP showed an oscillation that we explain in the light of a similar effect reported in other eclipses.

We found a time lag of about 15 min measured from the eclipse central phase in this city. We made an inspection of related fluctuations and dynamics from the computed rates of the temporal variation of temperature and RH. Trying to identify the influence of solar eclipses in similar environments we have made a broad inter-comparison with other observations of these variables in the Near East, northern Africa and in the United States. We compare our results with results obtained by other authors working with the December eclipse but in the United Arab Emirates and Oman, which showed dissimilar results. These inter-comparisons show how effectively the lower atmosphere can respond to a solar eclipse within a desert environment and others similar. As a preamble, a historical revision of temperature and humidity in the context of eclipse meteorology is also included.

Blow-away in the Extreme Low-mass Starburst Galaxy Pox 186

Eggen, Nathan R., Claudia Scarlata, Evan Skillman, and Anne Jaskot

The Astrophysical Journal, 912, 12, 2021

Pox 186 is an exceptionally small dwarf starburst galaxy hosting a stellar mass of ~10^5 M⊙. Undetected in H I (M < 10^6 M⊙) from deep 21 cm observations and with an [O III]/[O II] (5007/3727) ratio of 18.3 ± 0.11, Pox 186 is a promising candidate Lyman continuum emitter. It may be a possible analog of low-mass reionization-era galaxies. We present a spatially resolved kinematic study of Pox 186 and identify two distinct ionized gas components: a broad one with $\sigma > 400$ km s^{-1} and a narrow one with $\sigma < 30$ km s^{-1}. We find strikingly different morphologies between the two components and direct evidence of outflows as seen in the high-velocity gas. Possible physical mechanisms driving the creation of high-velocity gas seen in [O III] are discussed, from outflow geometry to turbulent mixing between a hot (10^6 K) star-cluster wind and cooler (10^4 K) gas clouds. We find a modest mass-outflow rate of 0.022 M⊙ yr^{-1} with a small mass-loading factor of 0.5, consistent with other low-mass galaxies. Finally, we compare the mass-loading factor of Pox 186 with extrapolations from numerical simulations and discuss possible reasons for the apparent discrepancy between them.

The Low-redshift Lyman-continuum Survey: [S II]-deficiency and the leakage of ionizing radiation

Wang, Bingjie, Timothy M. Heckman, Ricardo Amorín, Sanchayeeta Borthakur, John Chisholm, Harry Ferguson, Sophia Flury, Mauro Giavalisco, Andrea Grazian, Matthew Hayes, Alaina Henry, Anne Jaskot, Zhiyuan Ji, Kirill Makan, Stephan McCandliss, M. S. Oey, Göran Östlin, Alberto Saldana-Lopez, Daniel Schaerer, Trinh Thuan, Gábor Worseck, and Xinfeng Xu

The Astrophysical Journal, accepted for publication, arXiv:2104.03432

The relationship between galaxy characteristics and the reionization of the universe remains elusive, mainly due to the observational difficulty in accessing the Lyman continuum (LyC) at these redshifts. It is thus important to identify low-redshift LyC-leaking galaxies that can be used as laboratories to investigate the physical processes that allow LyC photons to escape. The weakness of the [S II] nebular emission lines relative to typical star-forming galaxies has been proposed as a LyC predictor. In this paper, we show that the [S II]-deficiency is an effective method to select LyC-leaking candidates using data from the Low-redshift LyC Survey, which has detected flux below the Lyman edge in 35 out of 66 star-forming galaxies with the Cosmic Origins Spectrograph onboard the Hubble Space Telescope. We show that LyC leakers tend to be more [S II]-deficient and that the fraction of their detections increases as [S II]-deficiency becomes more prominent. Correlational studies suggest that [S II]-deficiency complements other LyC diagnostics (such as strong Lyman-α emission and high [O III]/[O II]). Our results verify an additional technique by which reionization-era galaxies could be studied.

Resolving Structure in the Debris Disk around HD 206893 with ALMA

Neederlander, A., Hughes, A.M., Fehr, A.J., Flaherty, K.M., Su, K.Y.L., Moor, A., Chiang, E., Andrews, S.M., Wilner, D.J., Marino, S.

The Astrophysical Journal, 2021

Debris disks are tenuous, dusty belts surrounding main sequence stars generated by collisions between planetesimals. HD 206893 is one of only two stars known to host a directly imaged brown dwarf orbiting interior to its debris ring, in this case at a projected separation of 10.4 au. Here we resolve structure in the debris disk around HD 206893 at an angular resolution of 0.6" (24 au) and wavelength of 1.3 mm with the Atacama Large Millimeter/submillimeter Array (ALMA). We observe a broad disk extending from a radius of <51 au to 194^{+13}_{-2} au. We model the disk with a continuous, gapped, and double power-law model of the surface density profile, and fine strong evidence for a local minimum in the surface density distribution near a radius of 70 au, consistent with a gap in the disk with an inner radius of 63^{+8}_{-16} au and width 31^{+11}_{-7} au. Gapped structure has been observed in four other debris disks – essentially every other radially resolved debris disk observed with sufficient angular resolution and sensitivity with ALMA – and could be suggestive of the presence of an additional planetary-mass companion.

Biology

Energetic mechanisms for coping with changes in resource availability

Sonya K Auer, Julia R Solowey, Shreyas Rajesh, Enrico L Rezende

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Given current anthropogenic alterations to many ecosystems and communities, it is becoming increasingly important to consider whether and how organisms can cope with changing resources. Metabolic rate, because it represents the rate of energy expenditure, may play a key role in mediating the link between resource conditions and performance and thereby how well organisms can persist in the face of environmental change. Here, we focus on the role that energy metabolism plays in determining organismal responses to changes in food availability over both short-term ecological and longer-term evolutionary timescales. Using a meta-analytical approach encompassing multiple species, we find that individuals with a higher metabolic rate grow faster under high food levels but slower once food levels decline, suggesting that the association between metabolism and life-history traits shifts along resource gradients. We also find that organisms can cope with changing resource availability through both phenotypic plasticity and genetically based evolutionary adaptation in their rates of energy metabolism. However, the metabolic rates of individuals within a population and of species within a lineage do not all respond in the same manner to changes in food availability. This diversity of responses suggests that there are benefits but also costs to changes in metabolic rate. It also underscores the need to examine not just the energy budgets of organisms within the context of metabolic rate but also how energy metabolism changes alongside other physiological and behavioural traits in variable environments.

Late-stage pregnancy reduces upper thermal tolerance in a live-bearing fish

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Upper thermal limits are considered a key determinant of a population's ability to persist in the face of extreme heat events. However, these limits differ considerably among individuals within a population, and the mechanisms underlying this differential sensitivity are not well understood. Upper thermal tolerance in aquatic ectotherms is thought to be determined by a mismatch between oxygen supply and the increased metabolic demands associated with warmer waters. As such, tolerance is expected to decline during reproduction given the heightened oxygen demand for gamete production and maintenance. Among live-bearing species, upper thermal tolerance of reproductive adults may decline even further after fertilization due to the cost of meeting the increasing oxygen demands of developing embryos. We examined the upper thermal tolerance of live-bearing female Trinidadian guppies at different stages of reproduction and found that critical thermal maximum was similar during the egg yolking and early embryos stage but then declined by almost 0.5 °C during late pregnancy when oxygen demands are the greatest. These results are consistent with the hypothesis that oxygen limitation sets thermal limits and show that reproduction is associated with a decline in upper thermal tolerance.

Habitat restoration weakens negative environmental effects on telomere dynamics

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Habitat quality can have far-reaching effects on organismal fitness, an issue of concern given the current scale of habitat degradation. Many temperate upland streams have reduced nutrient levels due to human activity. Nutrient restoration confers benefits in terms of invertebrate food availability and subsequent fish growth rates. Here we test whether these mitigation measures also affect the rate of cellular ageing of the fish, measured in terms of the telomeres that cap the ends of eukaryotic chromosomes. We equally distributed Atlantic salmon eggs from the same 30 focal families into 10 human-impacted oligotrophic streams in northern Scotland. Nutrient levels in five of the streams were restored by simulating the deposition of a small number of adult Atlantic salmon Salmo salar carcasses at the end of the spawning period, while five reference streams were left as controls. Telomere lengths and expression of the telomerase reverse transcriptase (TERT) gene that may act to lengthen telomeres were then measured in the young fish when 15 months old. While TERT expression was unrelated to any of the measured variables, telomere lengths were shorter in salmon living at higher densities and in areas with a lower availability of the preferred substrate (cobbles and boulders). However, the adverse effects of these habitat features were much reduced in the streams receiving nutrients. These results suggest that adverse environmental pressures are weakened when nutrients are restored, presumably because the resulting increase in food supply reduces levels of both competition and stress.

The evolution of size-dependent competitive interactions promotes species coexistence

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Theory indicates that competing species coexist in a community when intraspecific competition is stronger than interspecific competition. When body size determines the outcome of competitive interactions between individuals, coexistence depends also on how resource use and the ability to compete for these resources change with body size. Testing coexistence theory in size-structured communities, therefore, requires disentangling the effects of size-dependent competitive abilities and niche shifts. Here, we tested the hypothesis that the evolution of species- and size-dependent competitive asymmetries increased the likelihood of coexistence between interacting species. We experimentally estimated the effects of size-dependent competitive interactions on somatic growth rates of two interacting fish species, Trinidadian guppies *Poecilia reticulata* and killifish *Rivulus hartii*. We controlled for the effects of size-dependent changes in the niche at two competitive settings representing the early (allopatric) and late (sympatric) evolutionary stages of a killifish-guppy community. We fitted the growth data to a model that incorporates species- and size-dependent competitive asymmetries to test whether changes in the competitive interactions across sizes increased the likelihood of species coexistence from allopatry to sympatry. We found that guppies are competitively superior to killifish but were less so in sympatric populations. The decrease in the effects of interspecific competition on the fitness of killifish and increase in the interspecific effect on guppies' fitness increased the likelihood that sympatric guppies and killifish will coexist. However, while the competitive asymmetries between the species changed consistently between allopatry and sympatry between drainages, the magnitude of the size-dependent competitive asymmetries varied between drainages. These results demonstrate the importance of integrating evolution and trait-based interactions into the research on how species coexist.

On the Origin of Coexisting Species

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Speciation is frequently initiated but rarely completed, a phenomenon hypothesized to arise due to the failure of nascent lineages to persist. Although a failure to persist often has ecological causes, key gaps exist between ecological and evolutionary theories that, if filled, would clarify when and why speciation succeeds or fails. Here, we apply ecological coexistence theory to show how the alignment between different forms of niche opportunity and niche use shape the initiation, progression, and completion of speciation. Niche evolution may drive coexistence or competitive exclusion, and an ability to coexist ecologically may help or hinder speciation. Our perspective allows progress towards unifying the origin and maintenance of species diversity across the tree of life.

Towards a more precise - and accurate - view of eco-evolution

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Over the past 15 years, the number of papers focused on 'eco-evo dynamics' has increased exponentially (Figure 1). This pattern suggests the rapid growth of a new, integrative discipline. We argue this overstates the case. First, the terms 'eco-evo dynamics' and 'eco-evo interactions' are used too imprecisely. As a result, many studies that claim to describe eco-evo dynamics are actually describing basic ecological or evolutionary processes. Second, these terms are often used as if the study of how ecological and evolutionary processes are intertwined is novel when, in fact, it is not. The result is confusion over what the term 'eco-evolution' and its derivatives describe. We advocate a more precise definition of eco-evolution that is more useful in efforts to understand and characterise the diversity of ecological and evolutionary processes and that focuses attention on the subset of those processes that occur only when ecological and evolutionary timescales are comparable.

The experimental range extension of guppies (*Poecilia reticulata*) influences the metabolic activity of tropical streams

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The ecological consequences of biological range extensions reflect the interplay between the functional characteristics of the newly arrived species and their recipient ecosystems. Teasing apart the relative contribution of each component is difficult because most colonization events are studied retrospectively, i.e., after a species became established and its consequences apparent. We conducted a prospective experiment to study the ecosystem consequences of a consumer introduction, using whole-stream metabolism as our integrator of ecosystem activity. In four Trinidadian streams, we extended the range of a native fish, the guppy (*Poecilia reticulata*), by introducing it over barrier waterfalls that historically excluded it from these upper reaches. To assess the context dependence of these range extensions, we thinned the riparian forest canopy on two of these streams to increase benthic algal biomass and productivity. Guppy's range extension into upper stream reaches significantly impacted stream metabolism but the effects depended upon the specific stream into which they had been introduced. Generally, increases in guppy biomass caused an increase in gross primary production (GPP) and community respiration (CR). The effects guppies had on GPP were similar to those induced by increased light level and were larger in strength than the effects stream stage had on CR. These results, combined with results from prior experiments, contribute to our growing understanding of how consumers impact stream ecosystem function when they expand their range into novel habitats. Further study will reveal whether local adaptation, known to occur rapidly in these guppy populations, modifies the ecological consequences of this species introduction.

Control of cell signaling by Arf GTPases and their regulators: Focus on links to cancer and other GTPase families

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The ADP-ribosylation factors (Arfs) comprise a family of regulatory GTP binding proteins. The Arfs regulate membrane trafficking and cytoskeleton remodeling, processes critical for eukaryotes and which have been the focus of most studies on Arfs. A more limited literature describes a role in signaling and in integrating several signaling pathways to bring about specific cell behaviors. Here, we will highlight work describing function of Arf1, Arf6 and several effectors and regulators of Arfs in signaling.

Mapping a mutation to its gene: The "fly lab" as a modern research experience.

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CourseSource. https://doi.org/10.24918/cs.2020.51

Although genetics is an invaluable part of the undergraduate biology curriculum, it can be intimidating to students as well as instructors: Students must reduce their reliance on memorization and dive deep into quantitative analysis, and instructors must make a long, rich history of genetics experiments clear, coherent, and relevant for students. Our Lesson addresses these challenges by having students map an unknown mutation to its gene using a modern suite of genetic tools. Students receive a *Drosophila melanogaster* strain with a mutation that causes the normally flat wing to bend at distinct sites along its length. Although we recently mapped this mutation to its gene, here we have renamed it "crumpled wing" (cw), an example of a pseudonym that you could use in the classroom. Like many standard "fly labs" that are taught at undergraduate institutions, this Lesson reinforces classic genetics concepts: students selectively mate fly strains to determine mode of inheritance, test Mendel's Laws, and three-point map an unknown mutation relative to known markers. But here, we expand on this tradition to simulate a more modern primary research experience: we greatly increase mapping resolution with molecularly-defined transgene insertions, deletions, and duplications; then cross-examine our data with key bioinformatic resources to identify a short-list of candidate cw genes. After extensive data interpretation and integration, students have been able to map cw to a single gene. This Lesson has a flexible design to accommodate a wide range of course structures, staffing, budgets, facilities, and student experience levels.

Experimental nitrogen fertilisation globally accelerates, then slows decomposition of leaf litter

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Plant litter decomposition is a central process in the carbon (C) cycle and sensitive to ongoing anthropogenic nitrogen (N) fertilisation. Previous syntheses evaluating the effect of N fertilisation on litter decomposition relied largely on models that define a constant rate of mass loss throughout decomposition, which may mask hypothesised shifts in the effect of N fertilisation on litter decomposition dynamics. In this meta-analysis, we compared the performance of four empirical decomposition models and showed that N fertilisation consistently accelerates early-stage but slows late-stage decomposition when the model structure allows for flexibility in decomposition rates through time. Within a particular substrate, early-stage N-stimulation of decomposition was associated with reduced rates of late-stage decay. Because the products of early- vs. late-stage decomposition are stabilised in soils through distinct chemical and physical mechanisms, N-induced changes in the litter decomposition process may influence the formation and cycling of soil C, the largest terrestrial C pool.

The plant pathogen enzyme AldC is a long-chain aliphatic aldehyde dehydrogenase

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Aldehyde dehydrogenases are versatile enzymes that serve a range of biochemical functions. Although traditionally considered metabolic housekeeping enzymes because of their ability to detoxify reactive aldehydes, like those generated from lipid peroxidation damage, the contributions of these enzymes to other biological processes are widespread. For example, the plant pathogen *Pseudomonas syringae* strain PtoDC3000 uses an indole-3-acetaldehyde dehydrogenase to synthesize the phytohormone indole-3-acetic acid to elude host responses. Here we investigate the biochemical function of AldC from PtoDC3000. Analysis of the substrate profile of AldC suggests that this enzyme functions as a long-chain aliphatic aldehyde dehydrogenase. The 2.5 Å resolution X-ray crystal of the AldC C291A mutant in a dead-end complex with octanal and NAD^+ reveals an apolar binding site primed for aliphatic aldehyde substrate recognition. Functional characterization of site-directed mutants targeting the substrate- and NAD(H)-binding sites identifies key residues in the active site for ligand interactions, including those in the "aromatic box" that define the aldehyde-binding site. Overall, this study provides molecular insight for understanding the evolution of the prokaryotic aldehyde dehydrogenase superfamily and their diversity of function.

Investigating the reaction and substrate preference of indole-3-acetaldehyde dehydrogenase from the plant pathogen *Pseudomonas syringae* PtoDC3000

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Aldehyde dehydrogenases (ALDHs) catalyze the conversion of various aliphatic and aromatic aldehydes into corresponding carboxylic acids. Traditionally considered as housekeeping enzymes, new biochemical roles are being identified for members of ALDH family. Recent work showed that AldA from the plant pathogen *Pseudomonas syringae* strain PtoDC3000 (PtoDC3000) functions as an indole-3-acetaldehyde dehydrogenase for the synthesis of indole-3-acetic acid (IAA). IAA produced by AldA allows the pathogen to suppress salicylic acid-mediated defenses in the model plant *Arabidopsis thaliana*. Here we present a biochemical and structural analysis of the AldA indole-3-acetaldehyde dehydrogenase from PtoDC3000. Site-directed mutants targeting the catalytic residues Cys302 and Glu267 resulted in a loss of enzymatic activity. The X-ray crystal structure of the catalytically inactive AldA C302A mutant in complex with IAA and NAD^+ showed the cofactor adopting a conformation that differs from the previously reported structure of AldA. These structures suggest that NAD^+ undergoes a conformational change during the AldA reaction mechanism similar to that reported for human ALDH. Site-directed mutagenesis of the IAA binding site indicates that changes in the active site surface reduces AldA activity; however, substitution of Phe169 with a tryptophan altered the substrate selectivity of the mutant to prefer octanal. The present study highlights the inherent biochemical versatility of members of the ALDH enzyme superfamily in *P. syringae*.

Disruption of long-chain base hydroxylation alters growth and impacts sphingolipid synthesis in *Physcomitrella patens*

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Sphingolipids have roles as membrane structural components and as bioactive molecules in plants. In *Physcomitrella patens*, 4-hydroxysphinganine (phytosphingosine, t18:0) is the predominant sphingolipid long-chain base (LCB). To assess the functional significance of t18:0, CRISPR-Cas9 mutagenesis was used to generate mutant lines lacking the sole SPHINGOID BASE HYDROXYLASE (SBH) gene encoding the hydroxylase responsible for converting

sphinganine (d18:0) to t18:0. Total sphingolipid content in sbh protonemata was 2.4-fold higher than in wild-type. Modest changes in glycosyl inositolphosphorylceramide (GIPC) glycosylation patterns occurred. Sphingolipidomic analyses of mutants lacking t18:0 indicated modest alterations in acyl-chain pairing with d18:0 in GIPCs and ceramides, but dramatic alterations in acyl-chain pairing in glucosylceramides, in which 4,8-sphingadienine (d18:2) was the principal LCB. A striking accumulation of free and phosphorylated LCBs accompanied loss of the hydroxylase. The sbh lines exhibited altered morphology, including smaller chloronemal cell size, irregular cell shape, reduced gametophore size, and increased pigmentation. In the presence of the synthetic trihydroxy LCB t17:0, the endogenous sphingolipid content of sbh lines decreased to wild-type levels, and the mutants exhibited phenotypes more similar to wild-type plants. These results demonstrate the importance of sphingolipid content and composition to *Physcomitrella* growth. They also illuminate similarities in regulating sphingolipid content but differences in regulating sphingolipid species composition between the bryophyte *P. patens* and angiosperm *A. thaliana*.

Does stress mess with rodents' heads? Influence of habitat amount and genetic factors in mandible fluctuating asymmetry in South American water rats (*Nectomys squamipes*, Sigmodontinae) from Brazilian Atlantic rainforest remnants

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Loss of developmental stability can lead to deviations from bilateral symmetry (i.e. Fluctuating Asymmetry - FA), and is thought to be caused by environmental and genetic factors associated with habitat loss and stress. Therefore, levels of FA might be a valuable tool to monitor wild populations if FA serves as an indicator of exposure to stress due to impacts of habitat loss and fragmentation. In studies examining FA and habitat fragmentation, FA levels are often explained by loss of genetic variation, though few studies have addressed FA's use as indicator of environmental impact. Here, we investigated whether habitat loss, genetic variation, and/or inbreeding affect the developmental instability in Brazilian Atlantic forest populations of a Neotropical water rat (*Nectomys squamipes*). We sampled individuals from eight sites within Atlantic forest remnants with different amounts of available forest habitat and assessed FA levels with geometric morphometric techniques using adult mandibles. We used observed heterozygosity (Ho) and inbreeding coefficient (Fis), from seven microsatellite markers, as a proxy of genetic variation at individual and population levels. Populations were not significantly different for shape or size FA levels. Furthermore, interindividual variation in both shape and size FA levels and interpopulational differences in size FA levels were best explained by chance. However, habitat amount was negatively associated with both interpopulational variance and average shape FA levels. This association was stronger in populations living in areas with <28% of forest cover, which presented higher variance and higher average FA, suggesting that *Nectomys squamipes* might have a tolerance threshold to small availability of habitat. Our work is one of the first to use FA to address environmental stress caused by habitat loss in small mammal populations from a Neotropical biome. We suggest that shape FA might serve as a conservation tool to monitor human impact on natural animal populations.

Behavioral thermoregulation in the fasted C57BL/6 mouse

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Under relatively cool ambient temperatures and a caloric deficit, mice will undergo daily torpor - a short-term regulated reduction in metabolic rate with a concomitant drop in body temperature. Mice can alternatively achieve metabolic savings by utilizing behavioral changes, such as seeking a warmer environment. However, there is a lack of knowledge about the behavioral interaction between torpor utilization and thermotaxis. That is, if a fasted mouse is faced with a choice between a warm environment not conducive for torpor, and a cool environment that will induce torpor, which scenario will the fasting mouse choose? Here, the temperature preferences of fasted mice were studied using a temperature gradient device that allows a mouse to freely move along a gradient of temperatures. C57BL/6 mice were implanted with temperature telemeters that recorded location, core temperature (Tb), and activity concurrently over a 23-h period in the thermal gradient. When the gradient was on, mice preferred the warm end of the gradient when fed (71 ± 4% of the time) and even more so when fasted (84 ± 2%). When the gradient was on, the fasted minimum Tb was significantly higher (34.4 ± 0.3 °C) than when the gradient was off (27.7 ± 1.6 °C). Further, fasted mice lost significantly more weight when the gradient was off despite maintenance of a metabolically favorable lower minimum Tb in this condition. These results indicate that fasted mice not only prefer warm ambient temperatures when given the choice, but that it is also the pathway with more favorable metabolic outcomes in a period of reduced caloric intake.

Physiological response to the odorant TMT in fully fed and calorically restricted laboratory mice

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2,3,5-trimethyl-3-thiazoline (TMT) is a chemical compound that is extracted from red fox urine and can be used to artificially simulate the presence of a predator. The purpose of this study was to test the hypothesis that TMT would block entry into torpor in the calorically restricted C57Bl/6 mouse. We first demonstrated that TMT induced fear in the mouse. Exposure to TMT induced an acute freeze response (67.2 ± 6.7% of time), as compared to 6.7 ± 1.7% when exposed to water. Further, exposure to TMT for 30 min led to elevated circulating corticosterone levels, 377 ± 33 ng/ml, as compared to 29 ± 4 ng/ml when exposed to water. When mice were exposed to TMT during the dark or light phase, body temperature (Tb) dropped by 1.7 ± 0.9 °C and 0.7 ± 1.1 °C, respectively, over the first 110 min after exposure. To determine whether TMT influences daily torpor, mice were calorically restricted and exposed to either water or TMT. Mice were exposed 30 min before the start of torpor, determined by the bout of the previous day. Exposure to TMT significantly ($p < 0.01$) blunted the fall in the minimum Tb from 28.8 ± 0.3 °C (water) to 30.1 ± 0.6 °C (TMT) and significantly ($p < 0.05$) decreased the amount of time Tb was under 32 °C, from 431 ± 48 min (water) to 292 ± 78 min (TMT). These results establish that mice perceived the scent of TMT as a physiologically stressful stimulus and that Tb response is modestly blunted in the presence of that stressor. Our experiment highlights the intricate interplay between predation risk and energy conservation.

Health Effects of Alternate Day Fasting Versus Pair-Fed Caloric Restriction in Diet-Induced Obese C57Bl/6J Male Mice

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Alternate day fasting (ADF) induces weight loss and improves various markers of health in rodents and humans. However, it is unclear whether the benefits of ADF are derived from the lower caloric intake of ADF or from the 24-h fasting period. Therefore, this study directly compared selected markers for health - such as glucose control, body weight, liver triglycerides, T cell frequencies, and others - in high-fat (60% calories from fat) diet-induced obese mice subjected to either ADF or caloric restriction (CR). Obese mice were randomly assigned to one of four groups: (1) ADF: remained on the high-fat diet, but fed on alternate days ($n = 5$), (2) PF: remained on the high-fat diet, but pair-fed to the ADF group ($n = 5$), (3) LF: moved to a chow ad libitum diet ($n = 5$; 17% calories from fat), and (4) HF: remained on the high-fat ad libitum diet ($n = 5$). An additional group of non-obese mice maintained on a chow diet since weaning were used as controls (CON: $n = 5$). After 10 weeks, ADF, PF, and LF mice ate fewer kcals, had a lower body mass, had smaller epididymal fat pads, improved glucose tolerance, and had a lower hepatic triglyceride content relative to HF mice ($p < 0.05$), but none reached that of CON mice in these measures. T cell frequencies of the spleen, blood, and mesenteric lymph nodes were reduced in ADF, PF, and HF compared to the CON group. Importantly, there were no significant differences between the ADF and PF groups in any of the measurements made in the current study. These data suggest that ADF, PF, and LF diets each lead to improved markers of health relative to high-fat diet-induced obese mice, and that the caloric restriction associated with ADF is the major factor for the noted improvements.

The physiological signature of daily torpor is not orexin dependent

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J Comp Physiol B. 2020 Jul;190(4):493-507. doi: 10.1007/s00360-020-01281-6. Epub 2020 May 12.

Under conditions of scarce food availability and cool ambient temperature, the mouse (Mus Musculus) enters into torpor, a state of transient metabolic suppression mediated in part by the autonomic nervous system. Hypothalamic orexins are involved in the coordination of behaviors and autonomic function. We tested whether orexins are necessary for the coordinated changes in physiological variables, which underlie torpor and represent its physiological signature. We performed simultaneous measurements of brain temperature, electroencephalographic, and electromyographic activity allowing objective assessment of wake-sleep behavior, and cardiovascular, respiratory, and metabolic variables in orexin knockout mice (ORX-KO) and wild-type mice (WT) during torpor bouts elicited by caloric restriction and mild cold stress. We found that torpor bouts in WT are characterized by an exquisitely coordinated physiological signature. The characteristics of torpor bouts in terms of duration and rate of change of brain temperature and electromyographic activity at torpor entrance and exit did not differ significantly between ORX-KO and WT, and neither did the cardiovascular, respiratory, and metabolic characteristics of torpor. ORX-KO and WT also had similar wake-sleep state changes associated with torpor bouts, with the exception of a significantly higher rapid-eye movement sleep time in ORX-KO at torpor entrance. Our results demonstrate that orexins are not necessary either for the normal physiological adaptations occurring during torpor in mice or for their coordination, suggesting that mechanisms different from orexin peptide signaling may be involved in the regulation and the coordination of these physiological responses.

Continuous and non-invasive thermography of mouse skin accurately describes core body temperature patterns, but not absolute core temperature

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Body temperature is an important physiological parameter in many studies of laboratory mice. Continuous assessment of body temperature has traditionally required surgical implantation of a telemeter, but this invasive procedure adversely impacts animal welfare. Near-infrared thermography provides a non-invasive alternative by continuously measuring the highest temperature on the outside of the body (Tskin), but the reliability of these recordings as a proxy for continuous core body temperature (Tcore) measurements has not been assessed. Here, Tcore (30 s resolution) and Tskin (1 s resolution) were continuously measured for three days in mice exposed to ad libitum and restricted feeding conditions. We subsequently developed an algorithm that optimised the reliability of a Tskin-derived estimate of Tcore. This identified the average of the maximum Tskin per minute over a 30-min interval as the optimal way to estimate Tcore. Subsequent validation analyses did however demonstrate that this Tskin-derived proxy did not provide a reliable estimate of the absolute Tcore due to the high between-animal variability in the relationship between Tskin and Tcore. Conversely, validation showed that Tskin-derived estimates of Tcore reliably describe temporal patterns in physiologically-relevant Tcore changes and provide an excellent measure to perform within-animal comparisons of relative changes in Tcore.

A role for the cortex in sleep-wake regulation

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Cortical and subcortical circuitry are thought to play distinct roles in the generation of sleep oscillations and global state control, respectively. Here we silenced a subset of neocortical layer 5 pyramidal and archicortical dentate gyrus granule cells in male mice by ablating SNAP25. This markedly increased wakefulness and reduced rebound of electroencephalographic slow-wave activity after sleep deprivation, suggesting a role for the cortex in both vigilance state control and sleep homeostasis.

Vocal learning in Savannah sparrows: Acoustic similarity to neighbours shapes song development and territorial aggression

Thomas, I, Doucet S., Norris, D.R., Newman, A.E.M., Williams, H., Mennill, D.J.
Animal Behaviour. 176:77-86. 2021

Vocal learning is a biologically rare adaptation that underpins both human language and the songs of songbirds. The adaptive value of vocal learning in birds is still poorly understood, but a growing body of literature suggests that vocal learning allows songbirds to gain a fitness advantage by adopting songs that are structurally similar to the songs of individuals in neighbouring breeding territories. In this study, we investigate patterns of song development, acoustic similarity, and territorial aggression in Savannah sparrows, Passerculus sandwichensis. Four years of field data reveal that Savannah sparrows routinely overproduce songs during development; more than half of young males sang more than one song type early in their first breeding season, before their repertoire underwent attrition to a single song that males maintained throughout the remainder of their lives. We also found that the attrition of song types is a selective process, with males retaining songs that are similar to the songs of their territorial neighbours. Males that sang songs that were more similar to their neighbours may have faced lower levels of territorial aggression, as indicated by lower numbers of aggressive calls. Our results provide support for the hypothesis that vocal learning in songbirds allows animals to produce songs that match territorial neighbours, possibly providing a benefit in terms of decreased aggression during territorial defence.

Mechanisms of cultural evolution in the songs of wild bird populations.

Williams, H.

Frontiers in Psychology, doi: 10.3389/fpsyg.2021.643343. 2021

Young songbirds draw the source material for their learned songs from parents, peers, and unrelated adults, as well as from innovation. These learned songs are used for intraspecific communication, and have well-documented roles for such functions as territory maintenance and mate attraction. The songs of wild populations differ, forming local “dialects” that may shift over time, suggesting that cultural evolution is at work. Recent work has focused on the mechanisms responsible for the cultural evolution of bird songs within a population, including drift, learning biases (such as conformity and rare-form copying), and selection (including sexual selection). In many songs or song repertoires, variability is partitioned, with some songs or song segments being stable and consistent, while others vary within the population and across time, and still others undergo population-wide transitions over time. This review explores the different mechanisms that shape the cultural evolution of songs in wild populations, with specific reference to a long-term investigation of a single population of philopatric Savannah sparrows. Males learn a single four-segment song during their first year and sing the same song thereafter. Within this song, the buzz segment is a population marker, and may be stable for decades – variant forms occur but eventually disappear. In contrast, the middle segment is highly variable both within the population and over time; changes in relative prevalence of different forms may be due to cultural drift or a rare-form learning bias. Within the introductory segment, a high note cluster was replaced by a click train between 1982 and 2010, following an S-shaped trajectory characteristic of both selective sweeps in population genetics and the replacement of one form by another in human language. In the case of the Savannah sparrows, this replacement may have been due to sexual selection. In subsequent generations, the number of clicks within trains increased, a form of cultural directional selection. In contrast to the narrowing of a trait’s range during directional selection in genetic systems, variation in the number of clicks in a train increased as the mean value shifted because improvisation during song learning allowed the range of the trait to expand. Thus, in the single short song of the Savannah sparrow, at least four different mechanisms appear to contribute to three different types of cultural evolutionary outcomes. In the future, it will be important to explore the conditions that favor the application of specific (and perhaps conditional) learning rules, and studies such as the ongoing song seeding experiment in the Kent Island Savannah sparrow population will help in understanding the mechanisms that promote or repress changes in a population’s song.

Chemistry

A Dynamic Study of Biochemical Self-Replication
Desire T. Gijima '10 and Enrique Peacock-López

Mathematics, 8:1042, 2020 doi:10.3390/math8061042

As it is well understood, in biological systems, small regulatory motifs are present at all scales, thus looking at simple negative feedback loops gives us some information on how autocatalytic systems may be affected by regulation. For a single template self-replication, we consider a plausible mechanism, which we reduce to a 2-variable dimensionless set of ordinary differential equations, (ODE). The stability analysis of the steady states allows us to obtain exact relations to describe two-parameter bifurcation diagrams. We include negative feedback to the reactants' input to study the effect of regulation in biochemical self-replication. Surprisingly, the simpler regulation has the largest impact on the parameter space.

A Delayed Modified Ricker Map and its Cicada-type Oscillations
Enrique Peacock-López

Physics Letters A, 384:126756, 2020 doi:10.1016/j.phjysleta.2020.126756

Without trying to develop a model for a biological system, we introduce a delay map that shows a large spike followed by 16 iterations of much smaller values. Upon variation of one of the parameters, we can get a 13 cycles stable oscillation. The analyses of the bifurcation diagrams for the delayed extended Ricker's map yield a straightforward approach to find parameter values for any periodicity. In particular, we determine the values for the 13 and 17 periodic oscillations. We also notice that the bifurcation diagrams show no chaotic regions, and their structures show self-similarity properties. In general, the bifurcation diagrams have self-similarity structures, where n-periodic oscillations change into (n-1)-periodic oscillations.

Chiral Oscillations and Spontaneous Mirror Symmetry: Breaking in a Simple Polymerization Model
William Bock '22 and Enrique Peacock-López

Symmetry, 12:1388, 2020 doi:10.3390/sym12091388

The origin of biological homochirality---defined as the preference of biological systems for only one enantiomer---has widespread implications in the study of chemical evolution and the origin of life. The activation---polymerization---epimerization—depolymerization (APED) model is a theoretical model originally proposed to describe chiral symmetry breaking in a simple dimerization system. It is known that the model produces chiral and chemical oscillations for certain system parameters, in particular, the preferential formation of heterochiral polymers. In order to investigate the effect of higher oligomers, our model adds trimers, tetramers, and pentamers. We report sustained oscillations of all chemical species and the enantiomeric excess for a wide range of parameter sets as well as the periodic chiral amplification of a small initial enantiomeric excess to a nearly homochiral state.

A Dynamic Study of Biochemical Self-Replication
Desire T Gijima '10 and Enrique Peacock-López

Prime Archives in Applied Mathematics, Chapter, Kyandoghere Kyamakya, Ed. Vide Leaf (Hyderabad, India), 2021

As it is well understood, in biological systems, small regulatory motifs are present at all scales, thus looking at simple negative feedback loops gives us some information on how autocatalytic systems may be affected by regulation. For a single template self-replication, we consider a plausible mechanism, which we reduce to a 2-variable dimensionless set of ordinary differential equations, (ODE). The stability analysis of the steady states allows us to obtain exact relations to describe two-parameter bifurcation diagrams. We include negative feedback to the reactants' input to study the effect of regulation in biochemical self-replication. Surprisingly, the simpler regulation has the largest impact on the parameter space

Kinetic Modeling of West Nile Virus Fusion Indicates an Off-Pathway State

Abraham Park ’22, Olivia Graceffa ’22, and Robert J. Rawle

ACS Infectious Diseases, 6:3260-3268, 2020 doi: 10.1021/acsinfecdis.0c00637

West Nile virus (WNV) is a prominent mosquito-borne flavivirus that causes febrile illness in humans. To infect host cells, WNV virions first bind to plasma membrane receptors, then initiate membrane fusion following endocytosis. The viral transmembrane E protein, triggered by endosomal pH, catalyzes fusion while undergoing a dimer-to-trimer transition. Previously, single-particle WNV fusion data was interrogated with a stochastic cellular automaton simulation, which modeled the E proteins during the fusion process. The results supported a linear fusion mechanism, with E protein trimerization being rate-limiting. Here, we present corrections to the previous simulation, and apply them to the WNV fusion data. We observe that a linear mechanism is no longer sufficient to fit the data. Instead, an off-pathway state is necessary; these results are corroborated by per virus chemical kinetics modeling. When compared with a similar Zika virus fusion model, this suggests that off-pathway fusion mechanisms may characterize flaviviruses more broadly.

Scientists' warning on invasive alien species

Petr Pyšek, Philip E Hulme, Dan Simberloff, Sven Bacher, Tim M Blackburn, James T Carlton, Wayne Dawson, Franz Essl, Llewellyn C Foxcroft, Piero Genovesi, Jonathan M Jeschke, Ingolf Kühn, Andrew M Liebhold, Nicholas E Mandrak, Laura A Meyerson, Aníbal Pauchard, Jan Pergl, Helen E Roy, Hanno Seebens, Mark van Kleunen, Montserrat Vilà, Michael J Wingfield, David M Richardson

Biol Rev Camb Philos Soc. 2020 Dec;95(6):1511-1534. doi: 10.1111/brv.12627. Epub 2020 Jun 25.

Biological invasions are a global consequence of an increasingly connected world and the rise in human population size. The numbers of invasive alien species - the subset of alien species that spread widely in areas where they are not native, affecting the environment or human livelihoods - are increasing. Synergies with other global changes are exacerbating current invasions and facilitating new ones, thereby escalating the extent and impacts of invaders. Invasions have complex and often immense long-term direct and indirect impacts. In many cases, such impacts become apparent or problematic only when invaders are well established and have large ranges. Invasive alien species break down biogeographic realms, affect native species richness and abundance, increase the risk of native species extinction, affect the genetic composition of native populations, change native animal behaviour, alter phylogenetic diversity across communities, and modify trophic networks. Many invasive alien species also change ecosystem functioning and the delivery of ecosystem services by altering nutrient and contaminant cycling, hydrology, habitat structure, and disturbance regimes. These biodiversity and ecosystem impacts are accelerating and will increase further in the future. Scientific evidence has identified policy strategies to reduce future invasions, but these strategies are often insufficiently implemented. For some nations, notably Australia and New Zealand, biosecurity has become a national priority. There have been long-term successes, such as eradication of rats and cats on increasingly large islands and biological control of weeds across continental areas. However, in many countries, invasions receive little attention. Improved international cooperation is crucial to reduce the impacts of invasive alien species on biodiversity, ecosystem services, and human livelihoods. Countries can strengthen their biosecurity regulations to implement and enforce more effective management strategies that should also address other global changes that interact with invasions.

ESR Dating Neanderthal Art and Pleistocene Paleoenvironments: An Example from Divje Babe I, Slovenia

Bonnie A.B. Blackwell, Ivan Turk, Matija Turk, Janez Turk, Joel I.B. Blickstien, and Anne R. Skinner

In: *Proceedings of NeanderART 2018 - Is There Palaeoart Before Modern Humans?*, Eds: Dario Seglie and Piero Ricchiardi. Centro Studi Silvio Pellico - Marcovalerio Eidzioni. 229-277, 2020

When first found in 1995 and dated in 1997, Divje Babe I's Neanderthal "flute", which was found closely associated with Mousterian artefacts and a hearth, constituted the first definitive evidence for artistic behaviours by Neanderthals. Since ESR has dated many Neanderthal and Middle Paleolithic sites, this study reexamines the dates and paleoclimatic interpretations for Divje Babe I, first dated in 1995-2003. Besides ~250,000 identified fossils, > 99% from Ursus spelaeus, in one of Slovenia's best documented Paleolithic site at Divje Babe I, its thick archaeological sequence housed many hearths, the multiperforated ursid femur musical instrument, Mousterian lithic and bone tools. Tools suitable for producing the musical instrument lay near it, and throughout the Mousterian layers. Ini-

tially, 11 layers had been dated by 44 independent standard ESR analyses on Ursus spelaeus teeth. Volumetrically averaged external radiation dose rates had been calculated from 146 sedimentary samples measured by neutron activation analysis. The dates had been coupled with sedimentary features, including granulometry, geochemistry, cryoturbation, éboulis production, cataclasis, pre- and post-depositional corrosion, secondary cementation, and aggregate formation, to build the longest Late Pleistocene paleoclimatic record in southeastern Europe.

Although the new study showed that one layer needed to be considered as three subhorizons, recalculating all the ESR ages yielded insignificant changes in the ESR ages, while the geochronological and paleoclimatic correlations with other global records have not changed substantively, despite the many more recent Late Pleistocene sequences dated since the initial study. From the absolute dates for the bracketing layers, the Middle-Upper Paleolithic transition at Divje Babe I dates at 44 ± 4 ka in mid-Marine Isotope Stage (MIS) 3, while the musical instrument dates to 61 ± 4 ka, correlating best with late MIS 4. Because carnivores could not have made this musically complex instrument, the Divje Babe I perforated femur remains the oldest known musical instrument.

Re-examining the Age of the Affad MSA Deposits in the Middle Nile Valley

P. Osypiński, S. Burrough, Anne Skinner, K. Standzikowski

Archaeometry, 2021, doi.org/10.1111/arcm.12670

We present data on the chronology of fluvial and aeolian sediments as well as ecofacts that allow us to indicate the timing of Middle Stone Age settlement in Affad on the Middle Nile. Previously published chronometric data based solely on (multi-grain) optically stimulated luminescence (OSL) dates suggested the extremely late settlement and usage of Middle Stone Age technology in North-East Africa during the Terminal Pleistocene (post-Last Glacial Maximum). The current analyses using multiple dating methods—multi- and single-grain OSL, thermoluminescence (TL), electron spin resonance (ESR) or accelerator mass spectrometry radiocarbon (AMS14C)—with OSL analyses carried out blind in three independent laboratories suggest this age is incorrect. More likely is that the site dates to about 50 ka. The comparison of dating results and methodological differences enable us to explore a spectrum of possible explanations. Here we infer the strong need to consider an appropriate methodology specific to the depositional context for indicating the age of fluvial sediments and prehistoric settlements at open-air sites of North-East Africa.

***Vibrio natriegens*: an ultrafast-growing marine bacterium as emerging synthetic biology chassis**

Josef Hoff, Benjamin Daniel, Daniel Stukenberg, Benjamin W Thuronyi, Torsten Waldminghaus, Georg Fritz

Environ Microbiol. 2020 Oct;22(10):4394-4408. doi: 10.1111/1462-2920.15128. Epub 2020 Jul 16.

The marine bacterium *Vibrio natriegens* is the fastest-growing non-pathogenic bacterium known to date and is gaining more and more attention as an alternative chassis organism to *Escherichia coli*. A recent wave of synthetic biology efforts has focused on the establishment of molecular biology tools in this fascinating organism, now enabling exciting applications - from speeding up our everyday laboratory routines to increasing the pace of biotechnological production cycles. In this review, we seek to give a broad overview on the literature on *V. natriegens*, spanning all the way from its initial isolation to its latest applications. We discuss its natural ecological niche and interactions with other organisms, unveil some of its extraordinary traits, review its genomic organization and give insight into its diverse metabolism - key physiological insights required to further develop this organism into a synthetic biology chassis. By providing a comprehensive overview on the established genetic tools, methods and applications we highlight the current possibilities of this organism, but also identify some of the gaps that could drive future lines of research, hopefully stimulating the growth of the *V. natriegens* research community.

Phage-Assisted Continuous Evolution (PACE): A Guide Focused on Evolving Protein-DNA Interactions

Serban C Popa, Ichiro Inamoto, Benjamin W Thuronyi, Jumi A Shin

ACS Omega. 2020 Oct 16;5(42):26957-26966. doi: 10.1021/acsomega.0c03508. eCollection 2020 Oct 27.

The uptake of directed evolution methods is increasing, as these powerful systems can be utilized to develop new biomolecules with altered/novel activities, for example, proteins with new catalytic functions or substrate specificities and nucleic acids that recognize an intended target. Especially useful are systems that incorporate continuous evolution, where the protein under selective pressure undergoes continuous mutagenesis with little-to-no input from the researcher once the system is started. However, continuous evolution methods can be challenging to implement and a daunting investment of time and resources. Our intent is to provide basic information and helpful suggestions that we have gained from our experience with bacterial phage-assisted continuous evolution (PACE) toward the evolution of proteins that bind to a specific DNA target. We discuss factors to consider before adopting PACE for a given evolution scheme with focus on the PACE bacterial one-hybrid selection system and what optimization of a PACE selection circuit may look like using the evolution of the DNA-binding protein ME47 as a case study. We outline different types of selection circuits and techniques that may be added onto a basic PACE setup. With this information, researchers will be better equipped to determine whether PACE is a valid strategy to adopt for their research program and how to set up a valid selection circuit.

Computer Science

Telescoping Filter: A Practical Adaptive Filter

David Lee ‘21, Samuel McCauley, Shikha Singh, *Max Stein ‘22*.

European Symposium on Algorithms (ESA), 2021.

Filters are fast, small and approximate set membership data structures. They are often used to filter out expensive accesses to a remote set S for negative queries (that is, a query x not in S). Filters have one-sided errors: on a negative query, a filter may say "present" with a tunable false-positive probability. A filter is adaptive if each query has false positive epsilon, regardless of what queries were made in the past. This requires "fixing" false positives as they occur. Adaptive filters not only provide strong false positive guarantees in adversarial environments but also improve performance on query practical workloads by eliminating repeated false positives. In this paper, we design a practical, provably adaptive filter: the telescoping adaptive filter (TAF).

Timely Reporting of Heavy Hitters using External Memory

S. Singh*, P. Pandey*, M. A. Bender, J. W. Berry, M. Farach-Colton, R. Johnson, T. Kroeger, C. Phillips. (* Joint first authors)

ACM Transactions on Database Systems Volume 46 Issue 4 December 2021 Article No.: 14 pp 1–35 https://doi.org/10.1145/3472392

The problem of finding heavy-hitters is extensively studied in the database literature. We study a real-time heavy-hitters variant in which an element must be reported shortly after they cross a certain threshold (and hence becomes a heavy hitter). We call this the Timely Event Detection (TED) Problem. The TED problem models the needs of many real-world monitoring systems, which demand accurate (i.e., no false negatives) and timely reporting of all events from large, high-speed streams, and with a low reporting threshold (high sensitivity).

Microteaching: Semantics, definition of a computer, running times, SIGCSE 2021 fractal trees, classes as encapsulation, and P vs NP

C. M. Lewis, K. Fisler, J. Hinz, D. J. Malan, J. E. Paley, M. A. Perez-Quinones, and S. Singh

SIGCSE Technical Symposium on Computer Science Education (SIGCSE TS '21)

SIGCSE is packed with teaching insights and inspiration. However, we get these insights and inspiration from hearing our colleagues talk about their teaching. Why not just watch them teach? This session does exactly that. Six exceptional educators will present their favorite piece of innovative lecture content just as they would to their students. The moderator, Colleen Lewis, will describe the central pedagogical move within the innovation and how this connects to education research. The goal of the session is to inspire SIGCSE attendees by highlighting innovative instruction by exceptional educators. The specific content of the innovative instruction may be applicable for some attendees, and the discussion of the underlying pedagogical move within each innovation can be applied across the attendees’ teaching.

Copy-on-Abundant-Write for Nimble File System Clones

Yang Zhan, Alexander Conway, Yizheng Jiao, Nirjhar Mukherjee, Ian Groombridge, Pace University; Michael A. Bender, Martin Farach-Colton, William Jannen, Rob Johnson, Donald E. Porter, Jun Yuan

ACM Transactions on Storage Volume 17 Issue 1 February 2021 Article No.: 5 pp 1–27 https://doi.org/10.1145/3423495

Making logical copies, or clones, of files and directories is critical to many real-world applications and workflows, including backups, virtual machines, and containers. An ideal clone implementation meets the following performance goals: (1) creating the clone has low latency; (2) reads are fast in all versions (i.e., spatial locality is always maintained, even after modifications); (3) writes are fast in all versions; (4) the overall system is space efficient. Implementing a clone operation that realizes all four properties, which we call a nimble clone, is a long-standing open problem.

This article describes nimble clones in Bε-tree File System (BetrFS), an open-source, full-path-indexed, and write-optimized file system. The key observation behind our work is that standard copy-on-write heuristics can be too coarse to be space efficient, or too fine-grained to preserve locality. On the other hand, a write-optimized key-value store, such as a Bε-tree or a log-structured merge-tree (LSM-tree), can decouple the logical application of updates from the granularity at which data is physically copied. In our write-optimized clone implementation, data sharing among clones is only broken when a clone has changed enough to warrant making a copy, a policy we call copy-on-abundant-write.

We demonstrate that the algorithmic work needed to batch and amortize the cost of BetrFS clone operations does not erode the performance advantages of baseline BetrFS; BetrFS performance even improves in a few cases. BetrFS cloning is efficient; for example, when using the clone operation for container creation, BetrFS outperforms a simple recursive copy by up to two orders-of-magnitude and outperforms file systems that have specialized Linux Containers (LXC) backends by 3–4×.

PerpLE: Improving the Speed and Effectiveness of Memory Consistency Testing

T. Melissaris, M. Markakis, K. Shaw and M. Martonosi

2020 53rd Annual IEEE/ACM International Symposium on Microarchitecture (MICRO), 2020, pp. 329-341, doi: 10.1109/MICRO50266.2020.00037.

Abstract: Even as most of today's computer systems have turned to parallelism to improve performance, their documentation often remains informal, incomplete or even incorrect regarding their memory consistency models. This leads to programmer and designer confusion and to buggy concurrent systems. Existing tools for empirical memory consistency testing rely on large numbers of iterations of simple multi-threaded litmus tests to perform conformance testing. The current approach typically employs thread synchronization at every iteration, which imposes a significant overhead and can reduce testing performance and efficiency. This paper proposes new litmus test variants called perpetual litmus tests, which allow for consistency testing without periteration synchronization. Perpetual litmus tests use arithmetic sequences in store operations to reduce the required synchronization points. We present PerpLE, a software suite that includes tools for the generation, execution, and analysis of perpetual litmus tests. We introduce an algorithm for determining the outcomes of perpetual litmus tests as well as a scalable linear heuristic algorithm. Evaluating the performance, scalability and ability of our tool to find outcomes of interest on an x86 system, we observe a wider variety of outcomes than litmus7 while experiencing runtime speedups over all litmus7 synchronization modes (8.89x over the default user mode). Compared to the default litmus7 synchronization (user) mode, PerpLE offers over four orders-of-magnitude improvement in the rate with which we detect target outcomes.

Resonance structures and aromaticity in capped carbon nanotubes

Jack Graver, Elizabeth Hartung, and Aaron Williams

Carbon 173 (6), 1082-1092, 2021.

The shape of a single-walled carbon nanotube's cylinder is described by its chiral indices, (n,m), and important properties of the nanotube are determined by this pair of values. In particular, a nanotube is metallic or quasi-metallic when n-m is a multiple of 3, and is otherwise a semiconductor. This paper characterizes the conjugated π-systems that can form on capped nanotubes in each case. When n-m is a multiple of 3, there is a fully conjugated π-system running along the nanotube's cylinder such that two-thirds of the hexagons are benzene rings and one-third are in a resonant set. In contrast, when n-m is not a multiple of 3, the pattern is broken along the length of the cylinder by two fracture lines. Surprisingly, and contrary to conventional thinking, these results are completely independent of the nanotube caps. The results are related to a similar characterization for open nanotubes by Ormsby and King, although in that case only a single fracture line is necessary. This new work is backed by the authors' previous results on the Clar numbers of fullerenes in general. It also provides new predictions for nanotubes and introduces the concept of the aromaticity ratio.

A Hamilton Cycle in the k-Sided Pancake Network
Ben Cameron, Joe Sawada, and Aaron Williams

Combinatorial Algorithms, 32nd International Workshop, IWOCA 2021, LNCS 12757, 137-151, 2021.

We present a Hamilton cycle in the k-sided pancake network and four combinatorial algorithms to traverse the cycle. The network's vertices are coloured permutations π=p1p2···pn, where each pi has an associated colour in {0,1,…,k-1}. There is a directed edge (π1,π2) if π2 can be obtained from π1 by a "flip" of length j, which reverses the first j elements and increments their colour modulo k. Our particular cycle is created using a greedy min-flip strategy, and the average flip length of the edges we use is bounded by a constant. By reinterpreting the order recursively, we can generate successive coloured permutations in O(1)-amortized time, or each successive flip by a loop-free algorithm. We also show how to compute the successor of any coloured permutation in O(n)-time. Our greedy min-flip construction generalizes known Hamilton cycles for the pancake network (where k=1) and the burnt pancake network (where k=2). Interestingly, a greedy max-flip strategy works on the pancake and burnt pancake networks, but it does not work on the k-sided network when k>2.

A Universal Cycle for Strings with Fixed-Content (which are also known as Multiset Permutations)
Joe Sawada and Aaron Williams

17th Algorithms and Data Structures Symposium, WADS 2021, LNCS 12808, 599-612, 2021.

We develop the first universal cycle construction for strings with fixed-content (also known as multiset permutations) using shorthand representation. The construction runs a necklace concatenation algorithm on cool-lex order for fixed-content strings, and is implemented to generate the universal cycle in amortized O(1)-time per symbol. This generalizes two previous results: a universal cycle for shorthand permutations by Ruskey, Holroyd, and Williams [Algorithmica 64 (2012)] and a universal cycle for shorthand fixed-weight binary strings by Ruskey, Sawada, and Williams [SIAM J. on Disc. Math. 26 (2012)]. A consequence of our construction is the first shift Gray code for fixed-content necklaces.

Block Dude Puzzles are NP-Hard (and the Rugs Really Tie the Reductions Together
Austin Barr '21, Calvin Chung '21, and Aaron Williams

33rd Canadian Conference on Computational Geometry, CCCG 2021, 114-125, 2021.

The computational complexity of agent-based box-pushing puzzles on grids is well-studied. In particular, the video game Sokoban was shown to be NP-hard, and later PSPACE-complete, in the mid-1990s, and dozens of variants have since been studied. In this paper, we change the top-down perspective to a side perspective, where the player and the boxes are subject to gravity, and the player is able to climb on top of boxes or walls of height one. We prove that determining whether a level is solvable is NP-hard when the goal is to reach the exit, or place the boxes on target locations. The former result was previously shown to be true with "Dig Dug gravity" (i.e. boxes are subject to gravity, but the player is not) by Friedman. We also consider the decision problems with pushable boxes being replaced by liftable blocks, or with pushable and liftable blox, or with general crates. In total, we establish NP-hardness for eight different decision problems, all based around a single reduction. The inspiration for this article was the classic TI 83/84 calculator game Block Dude, which requires reaching an exit in the presence of liftable blocks.

Turning Around and Around: Motion Planning through Thick and Thin Turnstiles
Aster Greenblatt, Oscar Hernandez, Robert Hearn, Yichao Hou, Hiro Ito, *Minwoo Kang '20*, Aaron Williams and Andrew Winslow

33rd Canadian Conference on Computational Geometry, CCCG 2021, 377-387, 2021.

We examine the computational complexity of turnstile puzzles, which are grid-based tour puzzles with walls and turnstiles. A turnstile is a wall that can be rotated in 90°increments, either clockwise or counterclockwise , around a central pivot when pushed by the player's token. In a 'thick' turnstile, the pivot and arms occupy cells of the grid, whereas in a 'thin' turnstile the pivot and arms occupy grid points and lines, respectively. We prove that reaching an exit is PSPACE-hard, even when restricted to just one of the following turnstiles types: , , , , , or. This establishes PSPACE-hardness for a dozen video games spanning several decades, including Kwirk (1989), Pokemon Ruby (2002), and Super Mario Odyssey (2017). Our hardness results are obtained by applying the motion planning framework in Jayson Lynch's PhD thesis A framework for proving the computational intractability of motion planning problems [MIT, 2020]. We also show that the decision problem can be solved in polynomial-time when restricted to or. We also formulate new open problems, and provide a survey of puzzles and games using turnstiles, which have also been called rotating doors, revolving gates, and spinning blocks.

Inside the Binary Reflected Gray Code: Flip-Swap Languages in 2-Gray Code Order
Joe Sawada and Dennis Wong and Aaron Williams

13th International Conference on Words, WORDS 21, LNCS, 2021.

A flip-swap language is a set S of binary strings of length n such that S∪{0^n} is closed under two operations (when applicable): (1) Flip the leftmost 1; and (2) Swap the leftmost 1 with the bit to its right. Flip-swap languages model many combinatorial objects including necklaces, Lyndon words, prefix normal words, left factors of k-ary Dyck words, and feasible solutions to 0-1 knapsack problems. We prove that any flip-swap language forms a cyclic 2-Gray code when listed in binary reflected Gray code (BRGC) order. Furthermore, a generic successor rule computes the next string when provided with a membership tester. The rule generates each string in the aforementioned flip-swap languages in O(n)-amortized per string, except for prefix normal words of length n which require O(n^1.864)-amortized per string. Our work generalizes results on necklaces and Lyndon words by Vajnovski [Inf. Process. Lett. 106(3):96−99, 2008].

Approximate Similarity Search Under Edit Distance Using Locality-Sensitive Hashing
Samuel McCauley

International Conference on Database Theory, 19:1-19:22, 2021

Edit Distance is a fundamental notion of similarity on text that is frequently used both for text generated by languages, and for applications like computational biology where the text corresponds to DNA sequences. Previous approaches have used one of two methods. The first is ``embeddings'': highly complicated data structures with extremely inaccurate (though quick to find) results. The second is ``trie''-based data structures, which have guaranteed accuracy but extremely slow running time. This work achieves a tradeoff in between these two points, achieving running time that depends on the desired accuracy of the results. This was done by changing a known embedding for edit distance into a locality-sensitive hash---a type of hash that is particularly effective for similarity search.

Support Optimality and Adaptive Cuckoo Fitlers
Tsvi Kopelowitz, Samuel McCauley, and Ely Porat

Algorithms and Data Structures Symposium, 556-570, 2021

Filters are a compressed data structure to rule out negative queries to a dataset. Recent work has focused on adaptive filters, who improve their performance when queries are made multiple times, but at the cost of practicality. In this paper, the authors ask if it is possible to create a filter that performs well on practical input sequences without being ``adaptive'' in an adversarial sense. The authors show theoretical bounds proving that a simple tweak of cuckoo filters---one of the best-performing filters in practice---achieves this kind of theoretical worst-case performance guarantee. They also give experimental results showing that the theory reflects effective practical performance.

PLDI '21: 42nd ACM SIGPLAN International Conference on Programming Language Design and Implementation
Stephen N. Freund, Eran Yahav

PLDI '21: 42nd ACM SIGPLAN International Conference on Programming Language Design and Implementation, Virtual Event, Canada, June 20-25, 2021.

Verifying the correctness of concurrent software with subtle synchronization is notoriously challenging. We present the Anchor verifier, which is based on a new formalism for specifying synchronization disciplines that describes both (1) what memory accesses are permitted, and (2) how each permitted access commutes with concurrent operations of other threads (to facilitate reduction proofs). Anchor supports the verification of both lock-based blocking and cas-based non-blocking algorithms. Experiments on a variety of concurrent data structures and algorithms show that Anchor significantly reduces the burden of concurrent verification.

The Anchor verifier for blocking and non-blocking concurrent software.
Cormac Flanagan, Stephen N. Freund

Proceedings for the ACM Programming Languages 4(OOPSLA): 156:1-156:29 (2020).

Welcome to PLDI 2021, the 42nd ACM SIGPLAN Conference on Programming Language Design and Implementation. Since the continued COVID-19 pandemic made our original plan to host PLDI 2021 in Quebec City infeasible, we have followed in the footsteps of PLDI 2020 and made this year's conference a virtual event held June 20-25, 2021. PLDI is a premier forum for programming language research, broadly construed, including design, implementation, theory, applications, and performance. PLDI contains outstanding research that extends and/or applies programming-language concepts to advance the field of computing. Novel system designs, thorough empirical work, well-motivated theoretical results, and new application areas are all welcome emphases at PLDI.

Geosciences

Plectatrypinae and Other Ribbed Atrypides Succeeding the End Ordovician Extinction Event, Central Oslo Region Norway

Baarli, B. G.

Journal of Paleontology, 95 (1), 75-10, 2020

Strata of the Solvik Formation in the central Oslo Region (upper Hirnantian through most of Aeronian) are very fossiliferous and provide a good record relating to the survival and recovery faunas after the end-Ordovician mass extinctions. The ribbed atrypide fauna is especially rich with 21 species present. Samples from most of these taxa have been sectioned to reveal internal structures for taxonomic study. Of these, 13 species belong to the family Atrypidae, three of which are described in the present paper; Dihelictera engerensis n. sp., Gotatrypa vettrensis n. sp., and Rhinatrypa henningsmoeni n. gen. The family Atrypidae follows a global pattern of recovery with an increase in diversity registered in upper Rhuddanian and further diversification in Aeronian strata. The focus of this paper is the family Atrypinidae, which shows a different pattern. They are common and fairly diverse near the base of the Rhuddanian in deeper waters and rare further up, especially in the Aeronian. One new genus, Bockeliena, and two new species, Plectatrypa rindi and Euroatrypa? sigridi are defined. The relationship between the subfamilies Spirigerininae and Plectatrypinae is clarified through thin sections of material from the Ordovician/Silurian boundary layers. The plectatrypids originated in Baltica through transitional species found in upper Katian to Hirnantian strata leading from the cosmopolitan Eospirigerina to the Plectatrypa lineage with imbricate ribbing and, separately, to Bockeliena and others with lamellose, widely spaced ornamentation. The Oslo Region probably acted as a nexus for survival and spread of brachiopods after the end-Ordovician mass extinction.

Seismic Detection of Ridging and Ice Deformation in Coastal Sea Ice Near Utqiagvik, Alaska

Marshall Borrus '20, Alice Bradley, and Kasey Aderhold

American Geophysical Union 2020

As climate change hits the Arctic hardest, coastal sea ice is forming later in the winter and seems to be less stable throughout the season. Shore-fast sea ice – coastal sea ice that is frozen to shore and stabilized by ice ridges extending down to the sea floor – protects the shoreline from erosion by large winter storms and provides a stable platform for travel and subsistence hunting activities in local communities. In order to form shore-fast ice, coastal ice develops deep ridges through repeated collisions with the drifting pack ice. This project examines seismic data from a nearby station in Utqiagvik, Alaska and shows that these ridge-building events can be detected at up to several kilometers from shore. Ridging events have a unique spectral signature and can be distinguished from breakout events (where unstable shore ice cracks and drifts away from shore), wind-related signals, and anthropogenic noise. This suggests that a network of seismic stations across the Arctic coastline could monitor shore-fast ice development where other methods are not available.

Rubber Ducks and Double Labs: Teaching Debugging Strategies in a Geoscience Class

Alice Bradley

American Geophysical Union 2020

Modern Climate is an upper-level geoscience course focused on what models can tell us about how Earth's climate system responds to anthropogenic forcings. In addition to learning about components of the climate system and how they interact, students are learning how climate models use energy and momentum transfer to make projections. Labs are a series of multi-week modeling projects using MATLAB, starting with a single-point energy balance model and scaling up to using GCM results from forcing experiments coordinated through CMIP6.

Many students take this class with no prior programming experience, and are learning programming fundamentals while applying them to these modeling and data analysis projects. Previously, there had been a weekly three-hour lab block where students could meet to work on these projects. For many students, the bulk of this time was spent asking for help debugging. In light of the move to online instruction, labs were rescheduled as two hour-long sessions during the week, which encouraged students to work more independently and try things before seeking help.

In light of all the previous struggles with debugging, Rubber Duck Debugging (where you explain each line of code to your duck) was taught at the beginning of the term as a strategy for finding errors in code (and thinking carefully about its construction), and all students were outfitted with a rubber duck for this purpose. This talk covers the lessons learned from both of these approaches.

Evaluating Global and Regional Observing Frameworks for Use in a Coordinated Arctic Observing System

Alice Bradley, Hajo Eicken, Olivia Astillero Lee, and Anna Gebruk

American Geophysical Union 2020

The geographic setting, diversity of stakeholders and data users, rapidly changing climate, and wide range of societal needs make the Arctic a region that would benefit from an internationally coordinated observing system. Global and regional observing systems exist to coordinate observations across sectors and/or national boundaries to leverage limited resources into widely-available observational data and information products. A similar system implemented in the Arctic region would need to cover a wide range of geophysical, ecological, and sociological observations, and address societal benefit areas ranging from local food security to global climate change. Several existing observing system frameworks are evaluated in the context of Arctic-specific requirements, ranging from global systems (e.g., Global Ocean Observing System, Global Cryosphere Watch, etc.) to regional-scale networks (e.g., Svalbard Integrated Observing System, Greenland Ice Sheet Observing System). Key features of these systems most relevant in the context of a Coordinated Arctic Observing System are identified and translated into specific guidance for implementation of coordinated observations through the Sustaining Arctic Observing Networks Roadmap for Arctic Observing and Data Systems.

Survey on Early Career Travel Support Highlights Inequalities in Access to Polar Science Events Across Geographic, Career Stage, and Indigenous Status

Clare Eayrs, Alice Bradley, Juan Höfer, and Valentina Savaglia

American Geophysical Union 2020

Scientific meetings, conferences, field schools and workshops provide essential networking and training opportunities for early career researchers. In highly international fields like polar sciences, attending these events can involve extensive travel. We surveyed Association of Polar Early Career Scientists members and other early career members of the polar science community to investigate the variability in travel support relative to costs across the early stages of a researcher's career. 190 respondents from 38 countries answered questions on the perceived availability of different types and sources of travel funding. Each respondent described up to three events they had attended in the preceding two years.

Cost of attendance prevented nearly three-quarters of respondents from participating in at least one career-relevant event over the survey period. Large disparities in what kinds of expenses are covered exist between geographic regions and funding mechanisms. Early career researchers frequently top up partial support with personal funds. Increased event-based travel support, and the timely notification of a travel award to benefit from early bird registration and cheaper travel and accommodation would help to reduce out of pocket expenses. Replacing the more common practice of travel reimbursement with a travel advance would remove another barrier to attendance.

With the Covid-19 pandemic, many meetings and workshops have moved online. While online meetings do not seem to be a total replacement for in-person interaction, they may boost the participation of often underrepresented groups. We encourage online event organizers to collect information from participants to see if the shift to an online setting has made the meeting accessible to a more diverse early career audience. Improving online access and addressing the disparities in travel support for career-relevant events will promote diversity and foster inclusion in the next generation of polar scientists.

The Arctic Observing Summit as a Mechanism to Develop and Link Observing Capacity from the Local to the Global Scale

Hajo Eicken, Peter Schlosser, Thorsteinn Gunnarsson, Alice Bradley, Raychelle Daniel, Jan René Larsen, Maribeth Murry, Peter Pulsifer, Ravi Darwin Sankar, and Sandra Starkweather

American Geophysical Union 2020

Rapid Arctic change impacts a range of communities and institutions, including Arctic Indigenous peoples, regional governments, pan-Arctic management bodies, and global society. Sustained observations of Arctic change inform response action, support prediction and decision-making, and provide insights into the evolution of Arctic systems in a global context. At present, we lack an integrated Arctic observing system that links the existing patchwork of observing projects, networks and programs across disciplines and scales. Such an integrated effort can provide a more comprehensive perspective on transformational Arctic change and serve an array of societal benefit areas identified in recent assessments. The Arctic Observing Summit (AOS) is a high-level, biennial summit to provide community-driven, science-based guidance for the design, implementation, coordination and long-term operation of such an international network of Arctic observing systems. The AOS provides a platform to address urgent observing needs across all of the Arctic system. It fosters international communication and coordination of long-term observing. Drawing on the 2020 AOS, we illustrate how a combination of activities and partnerships helped bridge observational scales and needs from the local to the global. As an activity under the Sustaining Arctic Observing Networks (SAON) initiative, AOS 2020 brought together Arctic observing program scientists, Indigenous peoples' organizations and community members, agency personnel, and representatives of global and regional observing initiatives to identify synergies between large-scale efforts and local information needs. SAON's Roadmap for Arctic Observing and Data Systems helps identify prioritized Shared Arctic Variables important to multiple information user groups and applications. Local needs are represented by an Indigenous Food Security Working Group charting out a path to expand Arctic Observing efforts to reflect holistic Indigenous worldviews through support and linking of local and regional activities. A Data Working Group focuses on the goal of a broadly networked, collaborative, interoperable Arctic digital system based on a co-production model and ethical data principles.

Filling in the Gap in Coastal Sea Ice Records with Community-Based Observations of Shore and Pack Ice Dynamics

Galen Cassidy '22, Alice Bradley, and *Marshall Borrus '20*

American Geophysical Union 2020

Coastal sea ice plays a critical role in communities along Alaska's Arctic Coast. Continued warming of the Earth's climate is resulting in shorter ice seasons, limiting the time coastal ice can protect the shoreline and serve as a stable platform for travel. With no immediate solution to the climate crisis apparent, detailed observation of its effects on shorefast sea ice may be able to mitigate some of the impacts on coastal communities. Coastal ice dynamics have proven consistently difficult to measure, with the presence of land contaminating some remote sensing products and violent interactions between shorefast and pack ice. Shore-based observations from community members may be a solution to filling that gap, but are limited to distances that can be seen by the human eye.

This project analyzes shore-based radar data in Utqiagvik, AK as compared to community observations collected through the SIZOnet project. This shows that records of certain types of ice events are reliably indicative of ice conditions beyond the range of sight, while others are only locally relevant. Ridging events associated with shore-lead closing are good indicators of large areas of high-concentration pack ice beyond, whereas lead opening events can be associated with any type of ice condition beyond the near-shore area. These results suggest how community observations could be used to validate remote sensing products near coastlines.

Opportunities for Observations in Support of Indigenous Food Systems in the Coastal Alaskan Walrus Ecosystem

Davis Collison '21 and Alice Bradley

American Geophysical Union 2020

Climate change disproportionately affects Native Alaskan communities in ways that impede Indigenous subsistence lifestyles and systems. In particular, sea ice along the coast of Alaska has become thinner, shorter-lived, and unpredictable which threatens the animals that depend on it, like the walrus, as well as subsistence hunters who are forced to change their traditional practices. Western scientific observations could be used to complement Indigenous Knowledge to mitigate these challenges. Indigenous groups and communities have created a framework, in their approach to food security/sovereignty, that can be used to assess how ongoing scientific observations could contribute to community needs.

This presentation uses the subsistence walrus hunt as a case study to show how existing datasets can help address these challenges: walrus populations are struggling in Alaska due to the changing sea ice season and hunters are struggling with increasingly dangerous conditions. The Sea Ice for Walrus Outlook (SIWO), a tool through the Arctic Research Consortium of the U.S. (ARCUS), coalates sea ice and weather forecasts as they relate to walrus hunting. These reports include data from Native Alaskan sea ice experts and the National Weather Service. We investigate the SIWO and additional sources of relevant observations in the context of the food security framework. This case study describes an aspect of food security/sovereignty in Alaska that reflects the challenges as well as potential pathways to mitigation and restoration through community-derived research priorities.

Single Fossil Organic Carbon Isotopes Illuminate a Mesoproterozoic Ecosystem

Phoebe Cohen, *Quinlan Byrne '20*, Christopher Junium, Heda Agic, and Susannah Porter

Geological Society of America Abstracts with Programs, 52 (6) doi: 10.1130/abs/2020AM-357771, 2020

Carbon isotopes are an essential tool for reconstructing Earth history, providing a view into the ancient carbon cycle, primary productivity, and more. The vast majority of these measurements have been done on bulk samples measuring either total inorganic or organic carbon. While these data have illuminated vast intervals of Earth's history, they provide a time- and community-averaged view of the carbon pool. Organic carbon isotope analyses of single microfossils are one approach that can provide a window into short-term environmental variability and can also reveal ecological data about enigmatic organic fossil groups. Here, we discuss new carbon isotopic data from individual acritarch microfossils of the Mesoproterozoic Velkerri Formation of Australia obtained via nano-EA mass spectrometry. Individual fossil $\delta^{13}C_{org}$ values range from -34.6‰ to -24.2‰ with a bulk $\delta^{13}C_{org}$ range of -34.6‰ to -32.11‰. Thus, fossil $\delta^{13}C_{org}$ is consistently equivalent to or heavier than the bulk value, with some samples enriched from the bulk by up to 10‰.

The purpose of this study is in part to resolve two models of eukaryotic evolution: the standard model, in which eukaryotes are restricted to oxygenated surface waters, and an alternative model, in which they are distributed throughout the water column under oxic and anoxic conditions. In a stratified ocean with a strong $\delta^{13}C$ and oxygen gradient, the $\delta^{13}C_{org}$ of individual microfossils within a given sample will be partially determined by their depth in the water column. The traditional model predicts that in a stratified, anoxic-at-depth ocean, the $\delta^{13}C$ of all microfossils sampled will be greater than the $\delta^{13}C$ of the bulk organic matter because the biological pump will leave the surface enriched. Under this model, microfossils should also have very similar $\delta^{13}C$ values because they will have sampled the same inorganic carbon pool. Under the alternative model however, the $\delta^{13}C$ of all the microfossils sampled will range from greater to less than the $\delta^{13}C$ of the bulk organic carbon. Our initial data from the Velkerri Formation tentatively support the alternative model: we find fossils that are equivalent to and heavier than the bulk, potentially suggesting that eukaryotic organisms were living in anoxic portions of the Mesoproterozoic water column. If confirmed, these results would require a re-imagining of the stem-to-crown transition within the eukaryotic clade.

Carbon Isotope Measurements of Single Organic-Walled Microfossils from the Tonian Chuar Group, USA Reveal Taxon-Specific Water Column Habitats

Heda Agic, Phoebe Cohen, Susanna Porter, and Christopher Junium

Geological Society of America Abstracts with Programs, 52 (6), doi: 10.1130/abs/2020AM-359172, 2020

Early eukaryotic cells are represented in the rock record as organic-walled microfossils (OWM). Although OWM constitute the bulk of the Precambrian fossil record, little is known about their affinities, habitat, or metabolism. It is unclear if the early eukaryotes were restricted to oxygenated surface waters or also inhabited the rest of the water column (predominantly anoxic ferruginous throughout Proterozoic), yet this information is critical to understand how the environment, e.g. stepwise ocean oxygenation, impacted eukaryotic evolution. Organic carbon isotope analyses of single microfossils can grant insight into short-term environmental variability as well as paleoecology of early eukaryotes. We analyzed C-isotopic composition of individual OWM from shales of the Tonian Chuar Group, Arizona, USA using nano-EA-IRMS method for analysis of single microfossils. OWM (>100) from 10 samples include smooth, ornamented, and envelope-bearing acritarchs, plus cell aggregates and filaments that were likely components of a benthic microbial mat. Fossil specimens show a wide spread of δ13C values in a sample (up to 22‰, average 12.5‰). Within well-defined species (e.g. Squamosphaera), spread is more limited (up to 5‰). Depleted values of mat-building prokaryotes Rugosoopsis, Polytrichoides, and Symplassosphaeridium (-33 to -26‰), lighter from bulkrock δ13Corg within samples by 5–16‰ are consistent with utilization of 13C-depleted C-sources from diffusing underlying pore waters, or DIC derived from respired planktonically-produced organic carbon. The most enriched δ13C values are observed in envelope-bearing Simia and ornamented Germinosphaera (c. -15‰), offset from the bulk δ13Corg by 3–11‰. Simia is consistently heavier than the mat builders in the same sample, up to 15.8‰, which suggests it probably incorporated 13C-enriched in surface waters, or utilized an alternative C-metabolism such as bicarbonate pumping. Polyphyletic taxon Leiosphaeridia shows a wide spread of 17‰ within a sample, likely reflecting different organisms living in different parts of the water column. Highest range in δ13COWM is observed in anoxic samples (FeHR/FeT>0.38), supporting the presence of a biological pump.

Single Organic Microfossils Carbon Isotopes During the Late Devonian Biotic Crisis, Insights into Ecology and Carbon Cycle Dynamics

Junium, Christopher K, Cohen, Phoebe, Uveges, Benjamin

Geological Society of America Abstracts with Programs, 52 (6) doi: 10.1130/abs/2020AM-357745, 2020

Organic carbon isotope analyses of single microfossils can provide a window into short-term environmental variability and reveal ecological data about enigmatic organic fossil groups. Here we apply a new technique for the $\delta^{13}C$ analysis of single organic walled microfossils (OWM) to samples taken from three sites in the Appalachian Basin (AB) of New York through the Late Devonian Biotic Crisis. Our data provide new insights into the nature of the Frasnian- Famennian carbon cycle in the AB, and also provide constraints on the paleoecology of enigmatic organic microfossils ubiquitous in Paleozoic shale successions.

The $\delta^{13}C$ of single leiospherid (smooth), acanthomorphic (spinose) and chitinozoan OWM range from -32 to -17‰, but average -25‰ across all samples and are consistent with organic matter of autochthonous origins. We observe no difference between the $\delta^{13}C_{OWM}$ of leiospheres and acanthomorphic acritarchs. This indicates that our data are an ecological signal, not a taxonomic one. Leiospheres and acanthomorphs are clearly sampling the same pool of carbon, had similar metabolisms and inhabited the same ecospace. Further, in accordance with morphological similarities between leiospherids and acathomorphs and modern algae, their $\delta^{13}C$ values are consistent with oxygenic photoautotrophic metabolisms. By contrast, chitinozoans are ^{13}C-depleted compared to both leiospheres and acanthomorphs, which indicates that the difference is being driven by metabolic, biosynthetic or carbon assimilatory pathways, or that chitinozoans are sampling a different carbon pool than acritarchs. We also observe a consistent 3 to 5‰ offset between $\delta^{13}C_{OWM}$ and $\delta^{13}C_{bulk}$ that we attribute to a $\delta^{13}C$ gradient in the AB water column where OWM utilized relatively ^{13}C-enriched dissolved inorganic carbon near the surface. Thus, the organisms producing the balance of the total organic carbon were assimilating ^{13}C-depleted C sources, either respired CO_2 or byproducts of fermentation. In this context, the deposition of Kellwasser black shales likely reflects a combination of an external influx of nutrients, shallowing of remineralization as a result of warming, and increased organic preservation. We also observe a systematic decrease in both $\delta^{13}C_{OWM}$ and $\delta^{13}C_{bulk}$ of 3‰ from shoreward to open ocean facies. This signal may reflect the effect of ^{13}C-enriched, weathering-derived DIC from riverine sources in this relatively enclosed epeiric seaway, a model that is consistent an estuarine mode of circulation that has been proposed for the AB.

Mercury Concentrations in the Appalachian Basin During the Late Devonian Kellwasser Events Shown No Evidence of Volcanism

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The paired Lower and Upper Kellwasser Events at the Frasnian-Famennian (F-F) stage boundary together represent one of the largest recognized biodiversity crises in Earth's history. Multiple triggers have been proposed as causes of one or both of these events, including large-scale volcanism; in particular, the emplacement of a large igneous province has been associated with the diversity depletions of the F-F boundary. Anomalous mercury enrichments in some Kellwasser-aged horizons in Morocco, Germany, and Russia have provided support for a volcanic trigger. Here, we expand the F-F mercury (Hg) record with geochemical data from six Kellwasser successions in the Appalachian Basin, a siliciclastic-dominated foreland basin that in the Late Devonian contained a shallow, epicontinental seaway. Our study sites reflect a gradient of paleoenvironments and lithologies, from shallow, near-terrestrial mixed silty shale and sandstone to deeper-water black and gray shale. At each locality, we present measurements of Hg concentration, as well as normalizations to total organic carbon (TOC), sulfur, and other trace metals (Al, Fe, Mo, U) to avoid common biases, including the tendency of Hg to complex with organic matter, sulphide and clay minerals, and/or hydrous Fe oxides.

We find no anomalous Hg spikes associated with the onset of either Kellwasser event in the Appalachian Basin. Hg concentrations were generally very low, with most samples < 50 ppb. Though our dataset covers a wide array of TOC values (< 0.1 – 10 wt%) and paleoenvironments, we observed a strong correlation between Hg concentration and TOC at most sites, indicating that Hg concentration of sediments deposited in the basin was generally controlled by local TOC and redox variability. The Appalachian Basin Hg record therefore does not support volcanism as a cause of the Kellwasser diversity depletions. We suggest that a re-evaluation of Hg anomalies in other localities may be necessary, since volcanism of the scale necessary to cause massive diversity depletions is likely to have left a record within the Appalachian Basin. Alternately, some of these anomalies might have resulted from regional volcanic activity or from the localized tectonic remobilization of older volcanogenic material.

Non-pollen Palynomorphs in Deep Time: Unravelling the Evolution of Early Eukaryotes

Agic, H. and Cohen, P. A.

Geological Society, London, Special Publications 511, SPS11-2020-223, 2021

Most of the Precambrian (> 541 Ma) fossil record, which includes the time before the onset of macroscopic multicellular life, consists of minute organically preserved remains of soft-bodied microorganisms, i.e. non-pollen palynomorphs (NPP). These microfossils include single-celled prokaryotic or eukaryotic organisms, filamentous sheets, and bacterial cellular aggregates, and occur in marine and lacustrine sediments through most of the Earth's history. Ancient NPP have informed our understanding of one of the biggest evolutionary steps in the history of life: the origin of the eukaryotic cell and the subsequent diversification of eukaryotic life before the evolution of macroscopic forms. The oldest widely accepted eukaryotic microfossils are large cells with opening structures and ornamentation from upper Palaeoproterozoic units in China and India. NPP diversify through Meso- and Neoproterozoic Eras, notably recording the oldest multicellular life around 1 billion years ago. In the latest Neoproterozoic, during the advent of animal life, the NPP record allows us to study the cryptic evolution of animals while they were exclusively small and poorly or non-mineralised before the appearance of organisms with hard parts. We review the current understanding of the early eukaryotic evolution and major advances in Precambrian palaeontology through the lens of the NPP record in deep time.

Living on the Edge: The Impact of Protracted Oxygen Stress on Life in the Late Devonian
Boyer, Diana, Aaron Martinez, Scott Evans, Phoebe Cohen, Emily Haddad, *Katherine Pippenger '20*, Gordon Love, Mary Droser

Palaeogeography, Palaeoclimatology, Palaeoecology, 110226, 2021

The Late Devonian records one of the most dramatic series of taxonomic and ecological turnovers in the history of life. The precise controls over the elevated extinctions and depressed origination rates at this time are not fully resolved, but reduced oxygen conditions undoubtedly played a role. A combined geochemical and paleonto-logical dataset from 17 localities across New York and Ohio provide a cohesive record of prolonged and repeated oxygen stress in the Appalachian Basin associated with numerous biotic turnovers through the Late Devonian. The trace fossil signal, captured as ichnofabric index data, and trace metal proxies (Mo, U, V) in this study provide insight into bottom water conditions, while biomarker data, including hopane/sterane, sterane carbon number ratios and Chlorobi-derived carotenoid abundances, in combination with organic-walled microfossil (OWM) abundances inform the nature of biological communities and redox conditions in the water column. These collective proxies allow us to compare the Lower and Upper Kellwasser Events, and the Hangenberg Biocrisis, with background conditions through the Late Devonian across a range of depositional environments. The results reveal that each of these three extinctions has a unique signal. Interestingly, the Hangenberg exhibits the greatest departure from background environmental conditions without comparable extinction rates, suggesting that prolonged oxygen stress throughout the Late Devonian removed vulnerable populations and limited the impact of this event. Further, variable signals and responses between bioevents likely indicate different drivers for each. This work adds to the narrative that the Late Devonian extinction event was unique among the "Big 5" and sets the stage for a more global-scale dissection of triggers, kill mechanisms, and responses.

Multi-Disciplinary Collectives in the Fight for Environmental Justice: How Scientific Activism, Legal Advocacy, and Community Organizing Address Environmental Inequities in Centreville, Illinois
José Constantine, Meleah Geertsma, Nicole Nelson, Lalila Jackson, and Cornelius Bennett

American Geophysical Union 2020

The residents of Centreville, Illinois, have for decades faced devastating flooding, sanitary sewer and drinking water issues due to poorly built and crumbling water infrastructure, and a larger social and political system that has turned its back on this Black, elderly and low-income community. As a result, the residents have had their homes destroyed, their health threatened, and their meager financial resources decimated. But they continue to be deeply committed to their community and each other, and now are working with a multi-disciplinary team of scientists, attorneys, historians, policy advocates and communications specialists to identify causes of the many water issues impacting the community and to push for solutions. We will describe the origins of this diverse collective and explain how scientists acting as community activists, lawyers donating their time as advocates, and a community developing its own organization of response have provided a new sense of hope that has been missing for decades. We will report the types of scientific information that has proven key to empowering and protecting residents as well as the struggles that the team has faced in finding scientists whose body of work aligns with the problems facing communities like Centreville. We will also highlight the challenges and pay-offs of participating in multi-disciplinary, community-centric teams following a deep engagement approach.

Modelling Soil Erosion Responses to Climate Change in Three Catchments of Great Britain
Ciampalini, R., Constantine, J.A., Walker-Springett, K.J., Hales, T.C., Ormerod, S.J., Hall, I.R.

Science of the Total Environment, 749 (141657) doi: 10.1016/j.scitotenv.2020.141657, 2020

Simulations of 21st century climate change for Great Britain predict increased seasonal precipitation that may lead to widespread soil loss by increasing surface runoff. Land use and different vegetation cover can respond differently to this scenario, mitigating or enhancing soil erosion. Here, by means of a sensitivity analysis of the PESERA soil erosion model, we test the potential for climate and vegetation to impact soil loss by surface-runoff to three differentiated British catchments. First, to understand general behaviours, we modelled soil erosion adopting regular increments for rainfall and temperature from the baseline values (1961–1990). Then, we tested future climate scenarios adopting projections from UKCP09 (UK Climate Projections) under the IPCC (Intergovernmental Panel on Climate Change) on a defined medium CO2 emissions scenario, SRES-A1B (Nakicenovic et al., 2000), at the horizons

2010–39, 2040–69 and 2070–99. Our results indicate that the model reacts to the changes of the climatic parameters and the three catchments respond differently depending on their land use arrangement. Increases in rainfall produce a rise in soil erosion while higher temperatures tend to lower the process because of the mitigating action of the vegetation. Even under a significantly wetter climate, warmer air temperatures can limit soil erosion by enhancing primary productivity and in turn improving leaf interception, infiltration-capacity, and reducing soil erodibility. Consequently, for specific land uses, the increase in air temperature associated with climate change can modify the rainfall thresholds to generate soil loss, and soil erosion rates could decline by up to about 33% from 2070 to 2099. We deduce that enhanced primary productivity due to climate change can introduce a negative-feedback mechanism limiting soil loss by surface runoff as vegetation-induced impacts on soil hydrology and erodibility offset the effects of increased precipitation. The expansion of permanent vegetation cover could provide an adaptation strategy to reduce climate-driven soil loss.

Poisoning Tallevast

Manigault-Bryant, J., *Bagwyn, R. '23*, Constantine, J.A.

in Cohen, J. and Chasman, D., eds., *Climate Action: Cambridge, Massachusetts, Boston Review Forum*, 16, 78-96. 2020

First, segregation blocked this Florida community from equal education and other public goods. Then the military–industrial complex sickened residents and destroyed their property.

Effect of Channel Tributaries on the Evolution of Submarine Channel Confluences (Espírito Santo Basin, SE Brazil)

Qin, Y., Alves, T.M., Constantine, J.A., Gamboa, D., Wu, S.

Geological Society of America Bulletin, 232 (1-2), 263-272 (doi: 10.1130/B35082.1), 2020

Confluences are geomorphologic features fed by distinct channel tributaries that record the contribution of multiple sediment sources. They are key features of both fluvial and submarine channels in geomorphologic and sedimentologic terms. Here, we use high-quality three-dimensional seismic data from SE Brazil to document the response of a submarine channel confluence to turbidity currents originating from a tributary. The studied channel system consists of a west tributary, an east tributary, and a postconfluence channel, with the last two comprising the main channel at present. Downstream from the confluence, changes in planform morphology and architecture were found due to the effect of turbidity currents sourced from the west tributary channel. A channel bend in the main channel curved toward the west when it was first formed but later curved toward the east, and so remains until the present day. This process led to the migration of the confluence point ~500 m to the east, and changed the bed morphology from discordant (where the beds of tributaries and main channels meet at an unequal depth) to concordant (where the beds of tributaries and main channels meet at approximately the same depth). In addition to the channel bend near the confluence, two other bends further downstream recorded significant changes with time, increasing channel sinuosity from 1.11 to 1.72. These three channel bends near the confluence accumulated a large volume of sediment at their inner banks, generating depositional bars. Multiple channel forms within the depositional bars indicate the occurrence of large-scale lateral migration near the confluence. Hence, turbidity currents from the west tributary are shown to influence the submarine channel by promoting lateral channel migration, confluence migration, increases in channel sinuosity, and the formation of large depositional bars. These variations near the confluence reveal a change in tributary activity and a shift in sediment sources from east to west on the continental shelf. Such a shift suggests variations in sedimentary processes on the continental shelf probably due to avulsions on Doce River Delta.

Can we Better Constrain the Timing of GNAIW/UNADW Variability in the Western Equatorial Atlantic and its Relationship to Climate Change During the Last Deglaciation?

Guilderson, TP, K Allen, JP Landers, VJ Ettwein, Mea S. Cook

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We have revisited the well-trod VM28-122 retrieved from the deep Colombian Basin, which includes sediments that reflect modern Upper North Atlantic Deep water and extends through the last deglaciation into the last glacial period when the site was bathed in Glacial North Atlantic Intermediate Water. Here, we leverage the Cariaco Basin's surface water radiocarbon reconstruction (reservoir age, and ΔR) on the IntCal20 timescale to recast the period of the last deglaciation with a newly constrained age model. Based on the revised age model, we observe that the multi-millennial decrease in benthic $\delta^{13}C$ and B/Ca (which record $\delta^{13}C$ of dissolved inorganic carbon and $\Delta[CO_3^{-2}]$, respectively) began at 18100±240 (95% CI) calibrated (cal) years BP, synchronous with Termination 1, as identified by changes in the Antarctic Ice Sheet composite and by the onset of rapid glacier recession in the Southern Hemisphere (Denton et al., 2010; Denton et al., 2021). The beginning of the decrease in benthic $\delta^{18}O$ is concurrent with the changes in carbon chemistry or at most a few hundred years later. It is no later than 17700±300 (95% CI) yrs BP in our record, at the putative start of Heinrich Stadial 1. With sufficient data density (more than 2-3 control points per kyr) and an independent record of past surface water radiocarbon variations, it is possible to achieve late glacial and deglacial chronologies with fidelities similar to those of ice cores. Doing so in more oceanographic locations should shed light more broadly on the mechanisms instrumental to abrupt climate change.

The Relationship Between Oxygenation, Productivity and Circulation in the Bering Sea During Late Pleistocene Glacial-interglacial Cycles

Jared Bathen '20 and Mea Cook

American Geophysical Union 2020

Changes in high-latitude biological and physical oceanographic processes have the potential to affect global climate. The efficiency of the biological pump, ocean circulation, and vertical mixing are all drivers of changes in ocean-atmosphere carbon dioxide flux and the CO2 storage of the ocean. It is hypothesized that lower sea level and expanded sea ice during glacial periods caused the expansion of nutrient-poor North Pacific Intermediate Water (NPIW). This in turn led to increased nutrient utilization in surface waters and greater CO2 storage in the glacial North Pacific. However, there are few long proxy records of the expansion of glacial NPIW. In this study, we present an opal wt. % record (productivity), a nitrogen isotope record (nutrient utilization), and a high resolution bioturbation index (seafloor oxygen concentration) from IODP site U1345. This site is in the middle of the present-day oxygen minimum zone (1008 m water depth) on the northern Bering Sea continental slope. These data span approximately 162 m of sediment representing the last 550 ky. Like other records from the region, the U1345 nitrogen isotope record is relatively high during glacial periods, consistent with the hypothesis that nutrient utilization is more complete during glacials. Homogenous, well-bioturbated sediment, reflecting relatively high seafloor oxygen concentration is associated with low to medium opal weight percent, reflecting low rates of diatom production. Laminated sediment (low oxygenation) is associated with medium to high opal weight percent (high productivity). It is clear that export production does not uniquely determine seafloor oxygenation. In addition, there is no evidence of consistently higher oxygenation during glacials, which we would expect with expanded glacial NPIW. This suggests the NPIW didn't extend to the depth of U1345, and/or a mechanism besides productivity and circulation drove preservation of laminations at this site.

Correlating Aleutian Tephra Layers Using Trace Element Ratios

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American Geophysical Union 2020

Analyzing both major and trace element concentrations in tephra layers is valuable for stratigraphy and correlation. With trace element chemistry we can distinguish tephras with similar major element concentrations. Using tephra chemistry data from three marine sediment cores from the Umnak Plateau in the southeast Bering Sea and three lake sediment cores from Sanak Island in the eastern Aleutians, we correlated tephra layers between the cores. Within these cores, we have analyzed up to 50 glass shards in each tephra layer for major elements using Electron Microprobe Analysis and for trace elements using Laser Ablation-Inductively Coupled Plasma-Mass Spectrometry. From 100 tephra layers, we analyzed ~3,200 glass shards for their major element compositions and ~900 shards for their trace element compositions to date. Identified compositions are comparable to the USGS Aleutian Arc Volcanic Whole Rocks database. For each tephra layer, the major element data showed either clustered data points or a range of compositions from basalt or basaltic andesite to andesite or rhyolite. This linear variability in major element chemistry indicates that magmatic evolution occurred during an eruption. We made initial tephra matches based on major element chemistry and guided by uncalibrated radiocarbon ages measured in the marine sediment core

HLY02-02-51JPC and published radiocarbon ages for the lake cores. We subsequently matched tephras between the marine sediment cores, between the lake sediment cores, and between marine and lake sediment cores. There are many tephras that do not appear in both the marine and lake settings, revealing smaller, proximal eruptions. Clustered major and minor element compositions are typically used for tephrochronology. Tephra layers with linear variability in composition are difficult to distinguish from one another. In order to match these samples, we use trace element ratios. Some trace element ratios can be diagnostic of particular eruptions because they remain constant even across a range of element concentrations. With the use of these ratios, we can find more tephra matches than were previously possible using solely clustered tephra compositions.

Nutrient Utilization and the Efficency of the Biological Pump During Late Pleistocene Glacial-interglacial Cycles in the Subarctic Pacific

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American Geophysical Union 2020

Reconstructing nutrient utilization in high-nutrient low-chlorophyll (HNLC) regions is important for understanding the relationship between biological productivity, carbon flux, and the climate system. Our research focuses on the HNLC region in the subarctic Pacific. Previously published nutrient utilization records in this region suggest that stronger stratification drives higher nutrient utilization during glacials. However, these studies have not provided an in-depth examination of how nutrient utilization varies by location within the HNLC region and whether the contributing factors are the same. With a sediment core from the edge of the HNLC region at the Bering Slope, IODP site U1345 (1008m water depth), we investigated changes in nutrient utilization over glacial-interglacial cycles in comparison to records from other parts of the HNLC region. We collected and analyzed $\delta^{15}N$, $\delta^{13}C$, and C/N of bulk organic matter, applying an isotope mass mixing model to remove the signal from terrigenous organic matter and estimate the marine phytoplankton end member. Compared to U1342, a site in the middle of the HNLC region, we find that U1345 has a) a larger fraction of terrigenous input, and b) overall higher nutrient utilization. The latter is likely due to increased iron and major nutrient transport to the euphotic zone from weaker stratification and shelf-slope exchange. Though it is hypothesized that stratification in this region strengthened through the late Pleistocene, the absence of a long-term trend at slope sites like U1345 suggests that local processes outweigh long-term region-wide stratification increase. While $\delta^{15}N$ at U1345 is relatively stable through the last 500 ky, $\delta^{15}N$ at U1342 increases and converges with U1345 toward the present. This suggests that the biological pump in the subarctic Pacific has become more efficient through time.

Storm Waves May be the Source of Some "Tsunami" Coastal Boulder Deposits

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Geophysical Research Letters, 01 June 2021 https://doi.org/10.1029/2020GL090775

Coastal boulder deposits (CBD) provide what are sometimes the only remaining signatures of wave inundation on rocky coastlines; in recent decades, CBD combined with initiation of motion (IoM) analyses have repeatedly been used as primary evidence to infer the existence of ancient tsunamis. However, IoM storm wave heights inferred by these studies have been shown to be highly inaccurate, bringing some inferences into question. This work develops a dimensionless framework to relate CBD properties with storm-wave hindcasts and measurements, producing data-driven relations between wave climate and boulder properties. We present an elevation-density-size-inland distance-wave height analysis for individual storm-transported boulders which delineates the dynamic space where storm-wave CBD occur. Testing these new relations against presumed tsunami CBD demonstrates that some fall well within the capabilities of storm events, suggesting that some previous studies might be fruitfully reexamined within the context of this new framework.

Coastal Boulder Deposits

Rónadh Cox

in R.J.N. Devoy, C. Cummins, B. Brunt, D. Bartlett and S. Kandrot, eds., *Shorelines: The Coastal Atlas of Ireland*, Cork University Press, 2021

Along Ireland's western coasts, areas of steep bedrock with open-ocean exposure host some of the world's most spectacular coastal boulder deposits (CBD). Perched above the highest high tide, CBD preserve a record of strong wave events that are capable of transporting large rocks against gravity, moving them upward and inland to sit stranded for years or even centuries before the next big event.

Drumming the Waves: Conveying Coastal Geoscience with Rhythm

Byrne, C. and Cox, Rónadh

EGU General Assembly vEGU21-1405, 0.5194/egusphere-egu21-1405, 2021

It is difficult to educate the public about geoscience and to create a message that will be heard in a noisy world. Coastal geoscience in particular—despite its growing importance as sea-level rises and storminess increases—has not penetrated effectively into the public sphere. High-energy coasts attract increasing numbers of visitors, most unaware of hazards related to stochastic wave behaviour. Photo-seekers in the Instagram era are driving up accidents in extreme environments, and it's increasingly common for people to be caught off guard and dragged into the ocean by rogue waves. Creative ways are needed to build awareness of the hazards, as well as the beauty, of high-energy coasts.

"Drumming the Waves," a musical representation of wave interactions with boulder beaches, is an NSF-funded musician-geoscientist collaboration. Informed by the shared physics of sound and water waves, the composition will showcase how mutual interference among wave sets gives rise to chaotic seas, rogue waves, and ocean swell; and how waves can be amplified unpredictably in the coastal zone. Minimalist compositional techniques are employed to overlap and superimpose multiple series of small and seemingly inconsequential rhythmic and melodic musical events, leading to composite results that are unpredictable, sometimes chaotic, and occasionally extreme.

A visceral artistic approach helps capture the 'feeling' of coastal waves and the impact of their interaction with boulder beaches, conveying sea states from serene calm to extreme chaos. Audio samples recorded at coastal locations in Ireland and the UK, both in air and beneath the ocean surface, are interwoven in the soundscape. We use wave sounds both in their natural audio state and in processed form. Creating new sounds by interacting field recordings of waves with electronic audio processers provides an artistic representation of the ubiquitous power and energy present in coastal environments. The temporal and erratic nature of coastal waves informs the musical structures on a macro level, exploring the contrast between the simple rhythm of tides and swell, and the irregular ephemerality of turbulent sea conditions. On a micro level, parallels between ocean and audio waves shapes are exploited to create novel musical events by shaping LFO (low frequency oscillator) and noise gates to mimic two-dimensional coastal wave models. Periodic emergence of unexpectedly large sound events mimics hazardous rogue wave generation.

We will build educational content around the music, to contextualise and explain it, and to draw attention specifically to boulder beaches, wave hazards, and the science of high-energy coasts. Simple worksheets showing wave spectra will be paired with percussion rhythms and melody that can be layered by students, either drumming and singing together, or mixing audio loops within a DAW (Digital Audio Workstation) such as GarageBand. This will permit students to build complex spectra from simple underlying wave forms. PowerPoint slides and explanatory text, pitched at the appropriate level, will be distributed to teachers for combined music/science learning. Using music to convey the science of wave interactions and wave amplification opens new doors and prospects for engaging and educating the public.

Distribution of Coastal Boulder Deposits on the Aran Islands, Ireland

Van Blunk, A., Kennedy, A.B., and Cox, Rónadh

Geological Society of America Abstracts with Programs, 52 (6) doi: 10.1130/abs/2020AM-355805, 2020

Coastal boulder deposits (CBD) are found on coasts and cliff tops all over the world, but those on the Aran Islands (off the west coast of Ireland) are among the best documented. Their combination of lithologic consistency and consistent wave climate (with strong prevailing wave approach direction), coupled with geomorphic variability, makes them an ideal candidate for detailed analysis of the relationship between local inshore wave height and CBD development.

These islands consist of three main land masses: Inishmore, Inishmaan, and Inisheer. Over centuries and millennia, waves from strong winter storms have created prominent CBD along cliffs and shore platforms on the Atlantic Coast of all three islands. However, locations with similar elevations and wave climates may or may not show CBD.

This study uses both existing CBD field measurements and new measurements extracted from satellite imagery and high-altitude orthophotographs, in conjunction with modeled hindcasts for near-shore sea states, to quantify relationships between CBD location, topographic setting, and wave climate. Initial results reveal a probabilistic relationship between inshore wave conditions and CBD occurrence, based on dimensionless analysis of wave heights and coastal elevations.

Further analysis will provide probabilities of occurrence as well as offer explanations for why locations with similar elevations and wave climates may show either the presence or absence of deposits. Dimensionless parameters introduced here, including a cliff elevation to wave height ratio, will allow this new approach to be translated to other sites. Determining these relationships will contribute to the ongoing need to better understand the interactions between extreme storm waves and rocky coasts.

Coastal Boulder Deposits: An Integral Part of Understanding Coastal Futures

Rónadh Cox

Geological Society of America Abstracts with Programs, 52 (6) doi: 10.1130/abs/2020AM-358456, 2020

Coastal boulder deposits (CBD) are supratidal accumulations of coarse clastic material. They are best known for their signature megagravel—individual clasts up to several hundred tonnes are recorded in some sites—but most deposits are dominated by less gargantuan boulder sizes, and may include abundant cobbles trapped in the interstices. Universal characteristics are that they occur on rocky coasts, above high tide, and are separated from the ocean by a bare bedrock platform. By preserving a record of high-energy marine inundation, CBD provide an opportunity to unlock long-term extreme-wave histories. But they are difficult to interpret, and difficult to date.

Debate continues as to whether individual CBD occurrences are the product of storm waves, or whether tsunami are required to emplace them. Recent advances in hydrodynamic analysis indicate that breaking or overtopping storm waves are capable of much greater force than had previously been realised, leading to an awareness that some CBD, previously interpreted as tsunami deposits, may in fact be the result of storms. Testing these ideas will take time, but is necessary to pinpoint the origins of local CBD occurrences. Equally important is the need to extract histories from CBD. The depositional ages of individual boulders are known in some cases, and those provide temporal anchor points for discrete transportation events. Regular monitoring of CBD—capturing the positions and structure of deposits—is also required to establish annual and decadal migration rates for boulder clusters and ridges. A combination of interdisciplinary approaches, as well as open-minded approaches to potential emplacement mechanisms, is the best way to attack these problems.

The value of unpacking the origins and transport histories of CBD is that ultimately they can serve as catalogues of extreme inundation events, linked also to the power of the emplacing waves: a boulder of a given size, at some known elevation and distance inland from the shoreline, requires a specific force in order to move. CBD event catalogues would therefore include specific information about flow strengths, making them unique in coastal event archives. Having these long-term records of powerful marine incursions will be valuable in long-term coastal planning. And knowing whether those inundations were due to tsunami or storm waves will permit more detailed and specific coastal hazard risk analysis.

Land-loss Rates for Indigenous Tribal Lands in Southern Louisiana are Higher than Overall Regional Rates

Devon Parfait '22 and Rónadh Cox

Geological Society of America Abstracts with Programs, 52 (6) doi: 10.1130/abs/2020AM-353890, 2020

Louisiana's land loss—famously estimated to be about a football field an hour—is increasingly well documented, but less attention is paid to rate variability, and how that intersects with issues of social justice. Native Americans, socially and physically marginalized in the southernmost wetlands, are disproportionately affected. The scale of the difference, however, is unquantified. We used GIS to measure changes over a 33-year period (1987-2020), to evaluate differences between regional land loss and land loss in tribal lands. We focused on three state-recognized tribes—the Isle de Jean Charles (IdjC), and Grand Caillou/Dulac (GCD) Bands of Biloxi Chitimacha Choctaw, and the Pointe-Au-Chien Tribe (PaC).

Unsupervised classifications of 1987 Landsat 5 and 2020 Sentinel 5 data (using bands 2, 6 and 11 for 2020, and bands 4 and 5 for 1987) were effective in distinguishing land from water. Heavily turbid bayous and wetlands are notoriously difficult to classify in GIS, so we also defined a "mixed water" category. The control area, from which we determined average regional land loss, was approximately 3272 km2 of southeastern Terrebonne Parish, and included the three tribal areas.

For the control area, land decreased from 64% to 50% over the 33 years: a 14% overall loss, or 0.4% per year on average. The tribal areas, in contrast, all showed higher rates. The GCD area lost 31% of the land to open water, PaC lost 17%, and IdJC lost 25%. These correspond to annual land-loss rates of 0.6% to 1.0% per year. In particular, GCD and IdJC have lost land at rates more than twice the regional background.

The roots of this problem lie in 19th century removals that drove indigenous peoples to vulnerable lands at the southern limits of the delta. Now, in the 21st century, these peoples suffer disproportionate impacts from ongoing subsidence and sea-level rise. The land-loss-forced resettlement of the IdJC community, considered America's first climate refugees, is a particularly strong example. And futures of Louisiana's other tribal communities in the southern delta are similarly unsafe. Ongoing work will include these groups, and will also generate more detailed land-loss rate profiles for each tribal area. Ultimately we aim to provide data that will help these marginalized peoples as they struggle to have their plight recognized.

Systems Thinking in Oceanography Courses

Lisa Gilbert

Geological Society of America Abstracts with Programs, 52 (6), doi: 10.1130/abs/2020AM-356749, 2020

Oceans are interconnected. Cold water sinks near the poles and hundreds of years later emerges at the surface near the equator. Tuna migrate across the Pacific and back for food and reproduction. Spilled oil is carried along currents from the Gulf of Mexico to the Atlantic. A tsunami travels from one side of the Indian Ocean to the other, flooding low-lying islands. Oceans also connect humans. For centuries we have traveled on ships. Today our global economy relies on the oceans as transportation corridors for food and other goods. However, the aesthetic, recreational, and economic values we place on the oceans are often in conflict with our dependence on them. We snorkel in coral reefs and find solace walking along a beach, but our burning of fossil fuels is stressing coral growth and causing rising sea levels that erode the shores and our ports.

With all the interconnections between oceans and societies, systems thinking is a natural fit for oceanography courses. Systems thinking helps equip students to address the grand challenges we face -- climate change, disease, poverty, natural disasters, and more -- by helping them establish a framework for evaluating feedback loops, equilibrium, and non-linear relationships between many interacting parts and processes. Oceanography or atmospheric science instructors with little experience in systems thinking can use materials from *InTeGrate* (e.g.,https://serc.carleton.edu/integrate/teaching_materials/syst_thinking/), which are available online for free, as a way to get started using many 'fluid' examples appropriate to their courses. The InTeGrate systems thinking essay and rubric give instructors an effective way to assess students' skill with the approach. Students learn ways to rigorously incorporate actions, attitudes, and motivations into a study of the complexity of the natural world. Further, if we want our students to be motivated to act, systems thinking is a transferable skill that can be used to help students to connect the cognitive and affective dimensions of learning.

A Systems Thinking Module for Middle School Earth Science Courses

Cameron Weiner, Lisa Gilbert

Geological Society of America Abstracts with Programs, 52 (6), doi: 10.1130/abs/2020AM-356755, 2020

The world is composed of many complex and interconnected systems, and disruptions in those systems give rise to complex problems such as water scarcity and soil degradation. Teaching systems thinking in Earth Science courses allows students to develop the big picture and connection-based thinking patterns needed to assess and address these problems. Recently, middle school Earth Science classes in the United States have changed from being taught in isolated units to having a greater focus on interconnectedness of natural and human systems through the Next Generation Science Standards. By integrating systems thinking into middle school science classes, students can begin to develop the pathways needed to think about the interconnected systems that make up environmental issues.

We introduce a series of new systems thinking activities, adapted from the InTeGrate undergraduate Systems Thinking module. These activities are designed to provide middle school students with the tools to assess complex issues of sustainability holistically. The systems thinking module will be available for free on the National Association of Geoscience Teachers' Teach the Earth portal and are designed for teachers to be able to pick and choose the activities that best fit into their online or in-person course. The module begins with activities that introduce systems thinking vocabulary and systems diagrams, then moves to activities addressing how rates, equilibrium, and feedback loops contribute to changes in systems over time. The module concludes with several activities that require students to assess an issue of sustainability through a variety of interconnected human and natural systems. The activities begin using simple water system examples such as the classroom sink and the school water supply system. The activities progress to more complex system examples with a greater focus on the interconnectedness between systems, ultimately assessing the issue of water scarcity in the United States through many connected human and natural systems like agriculture, energy, and the water cycle.

Teaching Geoscience Tools for Addressing Societal Grand Challenges: A Unique Study-Away Experience During COVID-19

Lisa Gilbert

Science Education and Civic Engagement: An International Journal, 12(2),32-33, 2020 http://new.seceij.net/articletype/teaching-and-learning/special-section-teaching-through-covid-19/

During the COVID-19 switch to remote learning Spring 2020 semester, I used the final 6 weeks of my oceanography course to teach specific topics and skills that would support students' ability to address complex, relevant problems. Students evaluated hazard and risk, worked with a variety of data, and learned the fundamentals of systems thinking. Much of the curricular material was based on published and peer-reviewed InTeGrate models, which were originally designed to be societally relevant. I introduced many of the examples and case studies originally planned related to hurricanes, oil spills, and climate. Although I did not teach public health, human biology, or other topics more closely related to the global pandemic, students reported that the course was exceptionally relevant. They had the opportunity to apply knowledge and skills learned, but not all chose to. Assignments were tailored to give students choice, and while some students had a great desire to process the health crisis, many had limited tolerance for discussions of COVID-19 and saw class as one of their only breaks from news and household discussions.

Empowering Students to Act

Lisa Gilbert

Perspectives on Earth and Space Science Education Research, 1(3), 2020 https://connect.agu.org/education/resources/pesser/vol1-issue3/

On the first day of the first oceanography class I took -- back in 1996 -- Professor Jim Carlton framed science as 5 Ps: phenomenon, pattern, process, prediction, and policy. Research begins with observing some phenomenon, he said, which if patiently described is likely to reveal a spatial or temporal pattern, driven by some underlying process. As scientists, we apply our understanding of the relevant processes to make predictions, and ultimately many of our findings inform individual and community decision-making, and broader policy. Importantly, that last P was introduced within the framework of science, not as something that happens separately, afterward. As science educators, I believe a crucial role we play right now is helping students to make the connections between understanding the world around them and putting that understanding into actions, both for the sake of humans' ability to live sustainably on Earth and for students' own self-efficacy.

Holocene Boulder Beach Eroded from Chromite and Dunite Sea Cliffs at Støypet on Leka Island (Northern Norway)

Markes E. Johnson

Journal of Marine Science and Engineering, 8, 644; doi: 10.3390/jmse8090644, 2020

This project examines the role of high-latitude storms degrading a Holocene coast formed by igneous rocks composed of low-grade chromite ore and dunite that originated within the Earth's crust near the upper mantle. Such rocks are dense and rarely exposed at the surface by tectonic events in the reconfiguration of old ocean basins. An unconsolidated boulder beach occupies Støypet valley on Leka Island in northern Norway, formerly an open channel 10,000 years ago when glacial ice was in retreat and rebound of the land surface was about to commence. Sea cliffs exposing a stratiform ore body dissected by fractures was subject to wave erosion that shed large cobbles and small boulders into the channel. Competing mathematical equations are applied to estimate the height of storm waves impacting the channel cliffs and the results are compared with observations on wave heights generated by recent storms striking the Norwegian coast with the intensity of an orkan (Norwegian for hurricane). Lateral size variations in beach clasts suggest that Holocene storms struck Leka Island from the southwest with wave heights between 5 and 7.5 m based on the largest beach boulders. This result compares favorably with recent high-latitude storm tracks in the Norwegian Sea and their recorded wave heights. The specific gravity of low-grade chromite ore (3.32 g/cm^2) sampled from the beach deposit exceeds that of rocks like limestone or other igneous rocks such as rhyolite, andesite, and basalt taken into consideration regarding coastal boulder deposits associated with classic hurricanes in more tropical settings.

Baja California's Coastal Landscapes Revealed: Excursions in Geologic Time and Climate Change

Markes E. Johnson

University of Arizona Press. 2021

Baja California is an improbably long and narrow peninsula. It thrusts out like a spear, parting the Mexican mainland from the Pacific Ocean. In his third installment on the Gulf of California's coastal setting, expert geologist and guide Markes E. Johnson reveals a previously unexplored side to the region's five-million-year story beyond the fossil coral reefs, clam banks, and prolific beds of coralline algae vividly described in his earlier books. Through a dozen new excursions, in Baja California's Coastal Landscapes Revealed, Johnson returns to these yet-wild shores to share his gradual recognition of another side to the region. Johnson reveals a geologic history that is outside the temporal framework of a human lifetime and scored by violent storms. We see how hurricanes have shaped coastal landscapes all along the peninsula's inner coast, a fascinating story only possible by disassembling the rocks that on first appraisal seem incomprehensible. Looking closely, Johnson shows us how geology not only helps us look backward but also forward toward an uncertain future. The landscape Johnson describes may be apart from the rest of Mexico, but his expert eye reveals how it is influenced by the unfolding drama of Planet Earth's global warming.

Upper Pleistocene and Holocene Storm Deposits Eroded from the Granodiorite Coast on Isla San Diego (Baja California Sur, Mexico)

Callahan, G., Johnson, M.E., Guardado-France, R., and Ledesma-Vázquez, J.

Journal of Marine Science and Engineering, 9, 555; doi: 10.3390/jmse9050555, 2021

This project examines the role of hurricane-strength events likely to have exceeded 119 km/h in wind speed that entered the Gulf of California from the open Pacific Ocean during Late Pleistocene and Holocene times to impact the granodiorite shoreline on Isla San Diego. Conglomerate dominated by large, ellipsoidal to sub-spherical boulders at the island's south end were canvassed at six stations. A total of 200 individual cobbles and boulders were systematically measured in three dimensions, providing the database for analyses of variations in clast shape and size. The project's goal was to apply mathematical equations elaborated after Nott (2003) with subsequent refinements to estimate individual wave heights necessary to lift igneous blocks from the joint-bound and exfoliated coast on Isla San Diego. On average, wave heights on the order of 3 m are calculated as having impacted the Late Pleistocene rocky coastline on Isla San Diego during storms, although the largest boulders more than a meter in diameter are estimated to weigh two metric tons and would have required waves in excess of 10 m for extraction. Described for the first time, a fossil marine biota associated with the boulder beds confirms a littoral to very shallow water setting correlated with Marine Isotope Stage 5e approximately 125,000 years ago. A narrow submarine ridge consisting in part of loose cobbles and boulders extends for 1.4 km to the southwest from the island's tip, suggesting that Holocene storms continued to transport rock debris removed from the shore. The historical record of events registered on the Saffir-Simpson Hurricane Wind Scale in the Gulf of California suggests that major storms with the same intensity struck the island in earlier times.

Late Pleistocene Boulder Slumps Eroded from a Basal Shoreline at El Confital Beach on Gran Canaia (Canary Islands, Spain)

Galindo, I., Johnson, M.E., Martín-Gonzálex, Romero, C., Vegas, J., Melo C., Ávila, S.P. and Sánchez, N.

Journal of Marine Science and Engineering, 9, 138; doi: 10.3390/jmse9020138

This project examines the role of North Atlantic storms degrading a Late Pleistocene rocky shoreline formed by basaltic rocks overlying hyaloclastite rocks on a small volcanic peninsula connected to Gran Canaria Island in the central region of the Canary Archipelago. Conglomerate dominated by large, ellipsoidal to angular boulders eroded from an adjacent basalt flow were canvassed at six stations distributed along 800m of the modern shore at El Confital on the outskirts of Las Palmas de Gran Canaria. A total of 166 individual basalt cobbles and boulders were systematically measured in three dimensions, providing the database for analyses of variations in clast shape and size. The project's goal was to apply mathematical equations elaborated after Nott (2003) and subsequent refinements to estimate individual wave heights necessary to lift basalt blocks from the layered and joint-bound sea cliffs at El Confital. On average, wave heights on the order of 4.2 to 4.5m are calculated as having impacted the Late Pleistocene rocky coastline at El Confital, although the largest boulders more than 2 m in diameter would have required larger waves for extraction. A review of the fossil marine biota associated with the boulder beds confirms a littoral to very shallow water setting correlated in time with Marine Isotope Stage 5e (Eemian Stage) approximately 125,000 years ago. The historical record of major storms in the regions of the Canary and Azorean islands indicates that events of hurricane strength were likely to have struck El Confital in earlier times. The outcrop is included in the Spanish Inventory of Geosites due to its high scientific value and must be properly protected and managed to ensure its conservation.

Global Biodiversity and Biogeography of Rhodolith-Forming Species

Rebelo, C.A., Johnson, M.E., Rasser, M.W., Silva, L., Melo, C.S., and Ávila, S.P.

Frontiers of Biogeography, 13 (1) e50646

Unattached nodules of calcareous red algae (Rhodophyta), known as rhodoliths, are widely reported and studied in places that extend from the tropics to polar latitudes. Factors controlling the distribution of the rhodolith-forming species remain poorly understood. A review of the global distribution of present-day rhodolith beds was undertaken, collating information on 106 rhodolith-forming species from 10 families, representing 21 genera distributed through 11 realms: 1) Arctic, 2) Temperate Northern Atlantic, 3) Temperate Northern Pacific, 4) Tropical Atlantic, 5) Western Indo-Pacific, 6) Central Indo-Pacific, 7) Eastern Indo-Pacific, 8) Tropical Eastern Pacific, 9) Temperate South America, 10) Temperate Australasia, and 11) Southern Ocean. The Central Indo-Pacific and Temperate Australasia proved to be the most diverse realms. Of 62 provinces across these realms, the Tropical Southwestern Atlantic, the Mediterranean Sea, and the Tropical East Pacific feature the highest diversity of rhodolith-forming species. A significant proportion of the 106 species (14.2%; 15 species) are endemic to a single biogeographic province. Species richness is weakly related to sampling effort (r^2=0.573) and unrelated to litoral area (r^2=0.012). Even when high latitude provinces are excluded from the analysis, no correlation between species richness and litoral was found (r^2 = 0.0005). A wider, evolutionary time framework revealed that the existence of marine barriers and the geological age of their final emplacement are key elements to explaining compositional differences between the rhodoliths of former contiguous areas (e.g., Pacific versus Atlantic shores of Panama and Costa Rica, in the Central America; eastern Mediterranean Sea versus Red Sea and Gulf of Aden). Finally, we propose that the lower diversity of the rhodolith-forming species in the tropical Pacific Ocean when compared to the Atlantic Ocean (23 versus 33 spp.), may be linked to the higher abundance of corals and coral reefs in the Pacific, which act as competitors with coralline algae for space.

Iapetus Shrugged: The Early Rifting Record of Laurentia in the New England and Quebec Appalachians

Karabinos, Paul, Crowley, J.L., Jaret, Steven J., Hodgin, E.B., and Macdonald, F.A.

Geological Society of America Abstracts with Programs, 52 (6), doi: 10.1130/abs/2020AM-357323, 2020

The Ediacaran breakup of Rodinia created the Laurentian margin and set the stage for the Paleozoic accretion of terranes during the Appalachian orogenic cycle. Cawood et al. (2001) proposed two pulses of rifting in the northern Appalachians at ca 570 and 540 Ma and suggested that the first separated Laurentia from Gondwanan cratons and that the second created Laurentian microcontinents. Waldron and van Staal (2001) suggested that the Dashwoods block in Newfoundland is a peri-Laurentian fragment that was reaccreted during the Taconic orogeny.

Rift volcanic rocks in the New England and Québec Appalachians include a 571 ± 5 Ma felsite from the Pinney Hollow Fm (PHF) in Vermont (Walsh and Aleinikoff, 1999) and a 554 +4/-2 Ma felsite from the Tibbit Hill Fm (THF) in Québec (Kumparapeli et al., 1989). We used CA-IDTIMS to date 7 zircon grains from the PHF- 562.37 ± .14 Ma, 6 grains from one THF sample- 553.70 ± .06 Ma, and 4 grains from another THF sample- 552.24 ± .07 Ma. We also used LA-ICPMS to date detrital zircon from undated basal rift clastic rocks that were locally derived from subjacent basement rocks in isolated rift graben in the Hoosac Range in northwestern MA and in the Chester dome in southeastern VT. In contrast, the Rowe Schist in MA, correlative with the PHF in VT, contains detrital zircon derived from many different sources in Laurentia, suggesting deposition by long-shore currents on an ocean-facing continental margin.

Our data suggest that deposition in deep water on a (hyper-?) extended continental margin was under way by 562 Ma and that the rifted blocks were never far removed from the Laurentian margin. Relict oceanic crust and obducted mantle occur outboard of the Pinney Hollow/Rowe belt along the contact with the Gondwanan-derived Moretown Fm. Evidence for reaccreted peri-Laurentian crust can be reinterpreted as Ordovician deposits in intra-arc or syn-collisional basins.

High Resolution Receiver Function Profile Beneath Connecticut and its Implications for the Tectonic History of Southern New England

Luo, Yantao, Long, Maureen, Karabinos, Paul, Kuiper, Yvette, Rondenay, Stephane

Geological Society of America Abstracts with Programs, 53 (1) doi: 10.1130/abs/2021NE-361885, 2021

The geology of southern New England has been shaped by a variety of past tectonic events, including Neoproterozoic continental rifting, multiple episodes of Paleozoic Appalachian orogenesis, and Mesozoic rifting. Southern New England shows diverse geologic features representing those past tectonic events. These include Proterozoic and early Paleozoic Laurentian units in the west, several Gondwanan-derived terranes that accreted during the Paleozoic to the east, and the Mesozoic Hartford Basin in the central portion of Connecticut. The Seismic Experiment for Imaging Structure beneath Connecticut (SEISConn) project involved the deployment of a dense array with 15 broadband seismometers across northern Connecticut from 2015 to 2019, in order to investigate how lithospheric structures beneath this region were deformed during these tectonic events and modified by subsequent events. The P-to-S receiver function analysis on SEISConn data shows that the westernmost part of Connecticut has a much deeper Moho than central and eastern Connecticut. The lateral transition shows as a vertical well-defined offset, with more than 15 km Moho depth reduction over ~20 km horizontal distance. The Moho step appears to be near the boundary between the Grenville orogenic belt to the west and the Gondwanan-derived Moretown terrane accreted during the Ordovician Taconic orogeny to the east, projected to the depth of the Moho. Receiver functions of the station CS03 located near the Moho step show Moho signals at multiple depths, suggesting that the Moho step is not simply the result of the juxtaposition of two landmasses with different crustal thickness. Possible models for its formation include over-thrusting of Grenville crust during the Moretown terrane accretion or modification by younger tectonic events after the Taconic orogeny. Another prominent feature imaged in this profile is a west-dipping positive velocity gradient in the lithospheric mantle, which is likely to be the Moho of a relict slab subducted during the later (Salinic, Acadian and/or perhaps Alleghanian) phases of the Appalachian orogenesis.

SKS Splitting and Upper Mantle Anisotropy Beneath the Southern New England Appalachians: Constraints from the Dense SEISCONN Array

Lopes, Ethan ‘20, Long, Maureen, Karabinos, Paul, Aragon, John, C.

Geological Society of America Abstracts with Programs, 53 (1) doi: 10.1130/abs/2021NE-361642, 2021

The crustal structure of eastern North America was created during two supercontinent cycles over the past 1.35 billion years. The present structure of the crust and mantle lithosphere beneath eastern North America preserves evidence of this complicated tectonic history, and new geophysical datasets are shedding light on its physical structure. Here we present seismic observations from the SEISConn array, a deployment of 15 broadband seismic stations across northern Connecticut. We studied the seismic waves that have passed through the upper mantle beneath southern New England, traveling nearly vertically beneath the seismic stations. Through measuring how these waves propagate differently in different directions (known as seismic anisotropy), we can learn about how past tectonic events have affected the deep part of the plate, and how the upper mantle is flowing today beneath southern New England. We find evidence for average fast splitting directions that are generally parallel to the absolute motion of the North American Plate. Additionally, there may be mantle upwelling (vertical flow) beneath the eastern portion of Connecticut today, and that the deep structure of the plate was altered by past tectonic events during Appalachian orogenesis.

SKS Splitting and Upper Mantle Anisotropy Beneath the Southern New England Appalachians: Constraints from the Dense SEISConn Array

Lopes, E. '20, Long, M.D., Karabinos, P., and Aragon, J.

Geochemistry, Geophysics, Geosystems, 21, 1-24 DOI 10.1029/2020GC009401, 2020

The geology of southern New England reflects subduction and terrane accretion during the Appalachian Orogeny and rifting during the breakup of Pangea. The presence of a low-velocity seismic anomaly in the upper mantle beneath New England suggests the possible presence of vertical mantle flow (upwelling). It remains poorly understood how the lithosphere beneath southern New England was deformed by past tectonic events; furthermore, the details of the present-day mantle flow field remain elusive. Observations of seismic anisotropy have the potential to constrain both past and present upper mantle deformation. Here, we present SK(K)S splitting observations at stations of the Seismic Experiment for Imaging Structure Beneath Connecticut array, a deployment of 15 broadband seismic stations across northern Connecticut. This linear array crosses a number of major terrane boundaries and traverses the Mesozoic Hartford Rift Basin in its central portion; its dense station spacing affords an opportunity to probe anisotropic structure on length scales that are relevant for the complex geology of southern New England. We find evidence for average fast splitting directions that are generally parallel to the absolute motion of the North American Plate, but in a few specific regions they are aligned with local tectonic boundaries. We document a striking decrease in splitting delay times (measured at low frequencies) from 0.9s at the western end of the array to 0.2s at the eastern end. We discuss several scenarios that might explain this observation, and explore the implications of our measurements for both present-day mantle flow and past lithospheric deformation beneath southern New England.

Mathematics and Statistics

Bipyramid Decomposition of Multi-crossing Link Complements
Colin Adams, *Gregory Kehne ‘16*

Communications in Analysis and Geometry, Volume 28, No. 3, 499-518, 2020.

Generalizing previous constructions, we present a dual pair of decompositions of the complement of a link L into bipyramids, given any multicrossing projection of L. When L is hyperbolic, this gives new upper bounds on the volume of L given its multicrossing projection. These bounds are realized by three closely related infinite tiling weaves.

Knotted Proteins: Gauss codes, Quandles and Bondles
C. Adams, *J. Devadoss ‘19*, M. Elhamdadi, A. Mashaghi

Journal of Mathematical Chemistry Vol. 58, 1711– 1736, 2020.

Proteins are linear molecular chains that often fold to function. The topology of folding is widely believed to define its properties and function, and knot theory has been applied to study protein structure and its implications. More that 97\% of proteins are, however, classified as unknots when intra-chain interactions are ignored. This raises the question as to whether knot theory can be extended to include intra-chain interactions and thus be able to categorize topology of the proteins that are otherwise classified as unknotted. Here, we develop knot theory for folded linear molecular chains and apply it to proteins.

For this purpose, proteins will be thought of as an embedding of a linear segment into three dimensions, with additional structure coming from self-bonding. We then project to a two-dimensional diagram and consider the basic rules of equivalence between two diagrams. We further consider the representation of projections of proteins using Gauss codes, or strings of numbers and letters, and how we can equate these codes with changes allowed in the diagrams. Finally, we explore the possibility of applying the algebraic structure of quandles to distinguish the topologies of proteins. Because of the presence of bonds, we extend the theory to define bondles, a type of quandle particularly adapted to distinguishing the topological types of proteins.

Superbridge and Bridge Indices for Knots
Colin Adams, Nikhil Agarwal, Rachel Allen, Tirasan Khandhawit, *Alex Simons ’21*, Rebecca Winarski, and Mary Wootters

Journal of Knot Theory and its Ramifications, Vol. 30, No. 2, 2150009, 2021.

We improve the upper bound on superbridge index sb[K] in terms of bridge index b[K] from sb[K] ≤ 5b[K] -3 to sb[K]\≤ 3b[K] - 1.

What is a Hyperbolic 3-Manifold?
Colin Adams

The Best Mathematical Writing of 2020, ed. by Mircea Princeton University Press, 2020.

A reprint of an introduction to hyperbolic 3-manifolds that first appeared in the Notices of the American Mathematical Society.

A Ghost Story
Colin Adams

Mathematical Intelligencer, Volume 42, Issue 3, 26-28, 2020.

A story told late at night to young mathematicians huddled in the hotel lounge late at night at a conference about mysterious happenings that seem to come true.

Algebrexit
Colin Adams

Mathematical Intelligencer, Volume 42, Issue 4, 33-35, 2020.

What happens when Algebra decides to exit the Mathematical Union.

Hyperbolic 3-Manifolds Boot Camp
Colin Adams

Mathematical Intelligencer, Volume 43, Issue 1, 40-41, 2021.

A mathematical boot-camp is surprisingly similar to a military boot camp.

All Tied Up
Colin Adams

Mathematical Intelligencer, Volume 43, Issue 2, 2021.

When two mathematicians are physically forced to collaborate on a big conjecture, does the math get done?

Conway's Knotty Past
Colin Adams

Mathematical Intelligencer, Volume 43, Issue 2, 2021.

An article honoring the contributions of John Conway to knot theory.

The Encyclopedia of Knot Theory
Colin Adams, Editor and Author of four articles

CRC Press, 2021.

This 941-page encyclopedia, edited by Colin Adams and five others, covers all aspects of knot theory.

Management Efficacy in a Metapopulation Model of White-Nose Syndrome
J. Duan, MM Malakhov, JJ Pellett, I. Phadke, J. Barber, and JC Blackwood

Natural Resource Modeling, e12304, 2021.

The fungal pathogen Pseudogymnoascus destructans (Pd) causes white-nose syndrome (WNS), an emerging disease that affects North American bat populations during hibernation. Pd has rapidly spread throughout much of the continent, leading to mass mortality and threatening extinction in several bat species. While previous studies have proposed treatment methods, little is known about the impact of metapopulation dynamics on these interventions. We investigate how the movement of bats between populations could affect the success of five WNS control strategies by posing and analyzing a two-population disease model. Our results demonstrate that vaccination will benefit from greater bat dispersal, but the effectiveness of treatments targeting fungal growth or disease progression can be expected to diminish. We confirm that successful control depends on the relative contributions of bat-to-bat and environment-to-bat contact to Pd transmission, and additionally find that the route of transmission can influence whether interpopulation exchange increases or decreases control efficacy.

Sharp Boundary Formation and Invasion Between Spatially Adjacent Periodical Cicada Broods
G Kye '21, J .Machta, KC Abbott, A. Hastings, W. Huffmyer, F. Ji, AM Liebhold, and JC Blackwood

Journal of Theoretical Biology, 515:110600, 2021.

Periodical cicadas, Magicicada spp., are a useful model system for understanding the population processes that influence range boundaries. Unlike most insects, these species typically exist at very high densities (occasionally >1000/ m2) and have unusually long life-spans (13 or 17 years). They spend most of their lives underground feeding on plant roots. After the underground period, adults emerge from the ground to mate and oviposit over a period of just a few days. Collections of populations that are developmentally synchronized across large areas are known as "broods". There are usually sharp boundaries between spatially adjacent broods and regions of brood overlap are generally small. The exact mechanism behind this developmental synchronization and the sharp boundary between broods remain unknown: previous studies have focused on the impacts of predator-driven Allee-effects, competition among nymphs, and their impacts on the persistence of off-synchronized emergence events. Here, we present a nonlinear Leslie-type matrix model to additionally consider cicada movement between spatially separated broods, and examine its role in maintaining brood boundaries and within-brood developmental synchrony that is seen in nature. We successfully identify ranges of competition and dispersal that lead to stable coexistence of broods that differ between spatial patches.

Political Economy of Renewable Resource Federalism

JN Sanchirco, JC Blackwood, B. Fitzpatrick, DM Kling, S Lenhart, MG Neubert, K Shea, CB Sims, and M. Springborn

Ecological Applications, 31:e0227, 2021.

The authority to manage natural capital often follows political boundaries rather than ecological. This mismatch can lead to unsustainable outcomes, as spillovers from one management area to the next may create adverse incentives for local decision making, even within a single country. At the same time, one-size-fits-all approaches of federal (centralized) authority can fail to respond to state (decentralized) heterogeneity and can result in inefficient economic or detrimental ecological outcomes. Here we utilize a spatially explicit coupled natural–human system model of a fishery to illuminate trade-offs posed by the choice between federal vs. state control of renewable resources. We solve for the dynamics of fishing effort and fish stocks that result from different approaches to federal management that vary in terms of flexibility. Adapting numerical methods from engineering, we also solve for the open-loop Nash equilibrium characterizing state management outcomes, where each state anticipates and responds to the choices of the others. We consider traditional federalism questions (state vs. federal management) as well as more contemporary questions about the economic and ecological impacts of shifting regulatory authority from one level to another. The key mechanisms behind the trade-offs include whether differences in local conditions are driven by biological or economic mechanisms; degree of flexibility embedded in the federal management; the spatial and temporal distribution of economic returns across states; and the status-quo management type. While simple rules-of-thumb are elusive, our analysis reveals the complex political economy dimensions of renewable resource federalism.

Educational Tool and Active-Learning Class Activity for Teaching Agglomerative Hierarchical Clustering

Cai, X., & Wang, Q.

Journal of Statistics Education, 28(3), 280-288, 2021.

To incorporate active learning and cooperative teamwork in statistics classroom, this article introduces a creative three-dimensional educational tool and an in-class activity designed for introducing the topic of agglomerative hierarchical clustering. The educational tool consists of a simple bulletin board and color pushpins (it can also be realized with a less expensive alternative) based on which students work collaboratively in small groups of 3–5 to complete the task of agglomerative hierarchical clustering: they start with n singleton clusters, each corresponding to a pushpin of a unique color on the board, and work step by step to merge all pushpins into one single cluster using the single linkage, complete linkage, or group average linkage criteria. We present a detailed lesson plan that accompanies the designed activity and also provide a real data example in the supplementary materials.

Variable Selection for Partially Linear Models via Bayesian Subset Modeling With Diffusing Prior

Wang, J., Cai, X., & Li, R.

Journal of Multivariate Analysis, 183, 104733, 2021.

Most existing methods of variable selection in partially linear models (PLM) with ultrahigh dimensional covariates are based on partial residuals, which involve a two-step estimation procedure. While the estimation error produced in the first step may have an impact on the second step, multicollinearity among predictors adds additional challenges in the model selection procedure. In this paper, we propose a new Bayesian variable selection approach for PLM. This new proposal addresses those two issues simultaneously as (1) it is a one-step method which selects variables in PLM, even when the dimension of covariates increases at an exponential rate with the sample size, and (2) the method retains model selection consistency, and outperforms existing ones in the setting of highly correlated predictors. Distinguished from existing ones, our proposed procedure employs the difference-based method to reduce the impact from the estimation of the nonparametric component, and incorporates Bayesian subset modeling with diffusing prior (BSM-DP) to shrink the corresponding estimator in the linear component. The estimation is implemented by Gibbs sampling, and we prove that the posterior probability of the true model being selected converges to one asymptotically. Simulation studies support the theory and the efficiency of our methods as compared to other existing ones, followed by an application in a study of supermarket data.

A Conversation with J. Stuart (Stu) Hunter
Richard De Veaux

Statistical Science, 34(4), p. 663-671, November 2020.

J. Stuart (Stu) Hunter has been an inspiration and mentor to a generation of statisticians, especially to those working in industry. Born on June 3, 1923 in Holyoke Massachusetts, Stu moved to Linden, New Jersey at the age of 2 where he spent the rest of his childhood, graduating from high school at age 16. After receiving a bachelor's degree in electrical engineering in 1947, he went on to receive a master's degree in applied mathematics in 1949 and a PhD in statistics in 1954, all from North Carolina State. His research centered on experimental design, in particular the study of fractional factorial designs and response surface methods. He was the founding editor of Technometrics. Stu joined the faculty at Princeton University as an assistant professor in the Engineering School in 1961. He was a first-rate teacher, and his courses at Princeton were often rated among the top courses at the University. The interviewer had the good fortune to take his Engineering Statistics course in 1970 which began a life-long friendship. Stu was a consultant for many companies and the co-author of the influential book Statistics for Experimenters with George Box and William Hunter. His short courses in industry were legendary. He served as the 1993 president of the American Statistical Association (ASA) and has received many honors and awards from the ASA, the ASQ and other organizations. The Stu Hunter Research Conference was established in 2013 to "honor one of the pioneers in applied statistics". Stu retired from Princeton in 1984, but remains active consulting, mentoring and traveling to this day.

Intro Stats, 6th ed.
Richard De Veaux

Pearson Inc, 2021.

A Formula for Enumerating Permutations With a Fixed Pinnacle Set
Alexander Diaz-Lopez, Pamela E. Harris, *Isabella Huang'18*, Erik Insko, and Lars Nilsen.

Discrete Mathematics, Volume 344, Issue 6, 112375, June 2021.

In 2017 Davis, Nelson, Petersen, and Tenner pioneered the study of pinnacle sets of permutations and asked whether there exists a class of operations, which applied to a permutation in Sn, can produce any other permutation with the same pinnacle set and no others. In this paper, we adapt a group action defined by Foata and Strehl to provide a way to generate all permutations with a given pinnacle set. From this we give an answer to a second question asked by Davis, Nelsen, Peterson, and Tenner, which asks for a closed non-recursive formula enumerating permutations with a given pinnacle set.

Functional Analysis Behind a Family of Multidimensional Continued Fractions: Part I
with *Ilya Amburg '14*

Publicationes Mathematicae Debrecen, Vol. 98, 2021.

Triangle partition maps form a family that includes many, if not most, well-known multidimensional continued fraction algorithms. This paper begins the exploration of the functional analysis behind the transfer operator of each of these maps. We show that triangle partition maps give rise to two classes of transfer operators and present theorems regarding the origin of these classes; we also present related theorems on the form of transfer operators arising from compositions of triangle partition maps. In the next paper, Part II, we will find eigenfunctions of eigenvalue 1 for transfer operators associated with select triangle partition maps on specified Banach spaces and then proceed to prove that the transfer operators, viewed as acting on one-dimensional families of Hilbert spaces, associated with select triangle partition maps are nuclear of trace class zero. We will finish in part II by deriving Gauss-Kuzmin distributions associated with select triangle partition maps.

Functional Analysis Behind a Family of Multidimensional Continued Fractions: Part II
with *Ilya Amburg '14*

Publicationes Mathematicae Debrecen, 2021.

This paper is a direct continuation of "Functional analysis behind a Family of Multidimensional Continued Fractions: Part I," in which we started the exploration of the functional analysis behind the transfer operators for triangle partition maps, a family that includes many, if not most, well-known multidimensional continued fraction algorithms. This allows us now to find eigenfunctions of eigenvalue 1 for transfer operators associated with select triangle partition maps on specified Banach spaces. We proceed to prove that the transfer operators, viewed as acting on one-dimensional families of Hilbert spaces, associated with select triangle partition maps are nuclear of trace class zero. We finish by deriving Gauss-Kuzmin distributions associated with select triangle partition maps.

Multi-Color Forcing in Graphs
Chassidy Bozeman, Pamela E. Harris, *Neel Jain'19, Ben Young'18,* and *Teresa Yu'19*

Graphs and Combinatorics 36, pages 1855–1868, 2020.

Let G=(V,E) be a finite connected graph along with a coloring of the vertices of G using the colors in a given set X. In this paper, we introduce multi-color forcing, a generalization of zero-forcing on graphs, and give conditions in which the multi-color forcing process terminates regardless of the number of colors used. We give an upper bound on the number of steps required to terminate a forcing procedure in terms of the number of vertices in the graph on which the procedure is being applied. We then focus on multi-color forcing with three colors and analyze the end states of certain families of graphs, including complete graphs, complete bipartite graphs, and paths, based on various initial colorings. We end with a few directions for future research.

Kostant's Partition Function and Magic Multiplex Juggling Sequences
Carolina Benedetti, Christopher R. H. Hanusa, Pamela E. Harris, Alejandro Morales, and *Anthony Simpson'19*

Annals of Combinatorics, 2020.

Kostant's partition function is a vector partition function that counts the number of ways one can express a weight of a Lie algebra g as a nonnegative integral linear combination of the positive roots of g. Multiplex juggling sequences are generalizations of juggling sequences that specify an initial and terminal configuration of balls and allow for multiple balls at any particular discrete height. Magic multiplex juggling sequences generalize further to include magic balls, which cancel with standard balls when they meet at the same height. In this paper, we establish a combinatorial equivalence between positive roots of a Lie algebra and throws during a juggling sequence. This provides a juggling framework to calculate Kostant's partition functions, and a partition function framework to compute the number of juggling sequences. From this equivalence we provide a broad range of consequences and applications connecting this work to polytopes, posets, positroids, and weight multiplicities.

On Lattice Point Weak b-Visibility
Allie Aird, Alberto Alonso, Samuel I. Cooper, Patrick M. Crossley, Pamela E. Harris, *Reuben Kaufman'19*,
George Kuliner, Robert J. Marino, Eric S. Piato, and Barbara J. Schweitzer
The Minnesota Journal of Undergraduate Mathematics, Volume 5, Academic Year 2019-2020.

For a fixed $b \in Z^+$, a point $(r, s) \in Z \times Z$ is b-visible from the origin if there exists a power function $f(x) = ax^b$ with $a \in Q$ such that f(0)=0 and f(r)=s, and no other point in the integer lattice belongs to the graph of f. In this article, we extend the definition of b-visibility given by Goins, Harris, Kubik, and Mbirika to the study of weak visibility. For a fixed $b \in Z^+$, we say that a point $Q = (h, k)$ in the array $\Delta_{m,n} = \{1, 2, . . . , m\} \times \{1, 2, . . . , n\}$ is weakly b-visible from a point $P = (r, s) \in Z^+ \times Z^+$ such that $P \in \Delta_{m,n}$ if no other point in $\Delta_{m,n}$ lies on the curve $f(x)= ((s-k)/(r-h)b)\ (x - h)^b + k$ between Q and P . In this paper we give necessary and sufficient conditions for determining if a point in Δm,n is weakly b-visible by an external point. We also show that for any point $P = (r, s)$ with $r > m$ and $s > n$, there exists a $b \geq 1$ such that every point in $\Delta_{m,n}$ is weakly b-visible from P . Our last result considers a fixed $b > 1$ and specifies the coordinates of a point P that weakly b-views every point in $\Delta_{m,n}$, and as a corollary we provide a way to determine the coordinates of the closest point to the array satisfying such a condition. We conclude by providing a few directions for future research.

A Novel Degree of Sex Difference in Laryngeal Physiology of Xenopus Muelleri: Behavioral and Evolutionary Implications

South, K., Klingenberg, B. and Leininger, E.

Journal of Experimental Biology 224 (7), jeb231712, 2021.

Characterizing sex and species differences in muscle physiology can contribute to a better understanding of proximate mechanisms underlying behavioral evolution. In Xenopus, the laryngeal muscle's ability to contract rapidly and its electromyogram potentiation allows males to produce calls that are more rapid and intensity-modulated than female calls. Prior comparative studies have shown that some species lacking typical male features of vocalizations sometimes show reduced sex differences in underlying laryngeal physiology. To further understand the evolution of sexually differentiated laryngeal muscle physiology and its role in generating behavior, we investigated sex differences in the laryngeal physiology of X. muelleri, a species in which male and female calls are similar in rapidity but different with respect to intensity modulation. We delivered ethologically relevant stimulus patterns to ex vivo X. muelleri larynges to investigate their ability to produce various call patterns, and we also delivered stimuli over a broader range of intervals to assess sex differences in muscle tension and electromyogram potentiation. We found a small but statistically significant sex difference in laryngeal electromyogram potentiation that varied depending on the number of stimuli. We also found a small interaction between sex and stimulus interval on muscle tension over an ethologically relevant range of stimulus intervals; male larynges were able to produce similar tensions to female larynges at slightly smaller (11–12 ms) inter-stimulus intervals. These findings are consistent with behavioral observations and present a previously undescribed intermediate sex difference in Xenopus laryngeal muscle physiology.

Statistics: The Art and Science of Learning from Data Evolutionary Implications

Agresti, A., Franklin, C., Klingenberg B.

Pearson, 5th Edition 733 pages, 2021.

Completions of Countable Excellent Domains and Countable Noncatenary Domains

S. Loepp and *T. Yu '20*

Journal of Algebra, 567, 210-228, 2021.

We find necessary and sufficient conditions for a complete local (Noetherian) ring containing the rationals to be the completion of a countable excellent local (Noetherian) domain. Furthermore, we find necessary and sufficient conditions for a complete local ring to be the completion of a countable noncatenary local domain, as well as necessary and sufficient conditions for it to be the completion of a countable noncatenary local unique factorization domain.

Structure of Spectra of Precompletions

E. Barrett '21, E. Graf '21, S. Loepp. K. Strong, and S. Zhang

Rocky Mountain Journal of Mathematics, 50, no. 6, 1965-1988, 2020.

Let T be a complete local (Noetherian) ring, and let A be a local subring of T such that the completion of A with respect to its maximal ideal is T. We investigate the possible structures of the partially ordered set Spec(A). Specifically, we explore the minimal prime ideals of A and their formal fibers, the maximal chains of prime ideals in A, and the number of prime ideals in A containing combinations of minimal prime ideals of A.

The Inverse Gamma Distribution and Benford's Law

S. Miller with *Rebecca F. Durst '17*, Chi Huynh, Adam Lott, Eyvindur A. Palsson, Wouter Touw, and Gert Vriend

The PUMP Journal of Undergraduate Research 3, 95-109, 2020.

According to Benford's Law, many data sets have a bias towards lower leading digits (about 30% are 1's). The applications of Benford's Law vary: from detecting tax, voter and image fraud to determining the possibility of match-fixing in competitive sports. There are many common distributions that exhibit such bias, i.e. they are almost Benford. These include the exponential and the Weibull distributions. Motivated by these examples and the fact that the underlying distribution of factors in protein structure follows an inverse gamma distribution, we determine the closeness of this distribution to a Benford distribution as its parameters change.

Central Limit Theorems for Compound Paths on the 2-Dimensional Lattice
S. Miller with Evan Fang, Jonathan Jenkins, Zack Lee, Daniel Li, Ethan Lu, Dilhan Salgado, Joshua Siktar

Fibonacci Quarterly 3, 208-225, 2020.

We prove Gaussian behavior for generalized Zeckendorf decompositions in 2-dimensions.

Higher Order Fibonacci Sequences from Generalized Schreier Sets
S. Miller with Hung Viet Chu, Zimu Xiang

Fibonacci Quarterly 3, 249-253, 2020.

We find recurrence relations for generalized Schreier Sets.

On the Sum of *k*-th Powers in Terms of Earlier Sums
S. Miller with Enrique Trevino

The College Mathematics Journal 48, 123-128, 2020.

For k a positive integer let $S_k(n) = 1^k + 2^k + \cdots + n^k$, *i.e.*,$S_k(n)$ is the sum of the first k-th powers. Faulhaber conjectured (later proved by Jacobi) that for k odd, $S_k(n)$ can be written as a polynomial of $S_1(n)$, and for k even, $S_k(n)$ can be written as $S_2(n)$ times a polynomial of $S_1(n)$ for example $S_3(n) = S_1(n)^2$, $S_4(n) = S_2(n)(65S_1(n)-15)$. We give a proof of a variant of this result, namely that for any k there is a polynomial $gk(x, y)$ such that $S_k(n) = g(S_1(n), S_2(n))$. The novel proof yields a recursive formula to evaluate $S_k(n)$ as a polynomial of m n that has roughly half the number of terms as the classical recursive formula that uses Pascal's identity

Deterministic Zeckendorf Games
S. Miller with Ruoci Li, Xiaonan Li, *Clay Mizgerd '22*, *Chenyang Sun '21*, Dong Xia, and Zhyi Zhou

Fibonacci Quarterly 58, no. 5, 152-160, 2020.

Zeckendorf [Ze] proved that every positive integer can be written uniquely as the sum of non-adjacent Fibonacci numbers. We further explore a two-player Zeckendorf game introduced in [BEFM1, BEFM2]: Given a fixed integer n and an initial decomposition of $n=nF_1$, players alternate using moves related to the recurrence relation $F_{n+1}=F_n + F_{n1}$, and the last player to move wins. We improve the upper bound on the number of moves possible and show that it is of the same order in n as the lower bound; this is an improvement by a logarithm over previous work. The new upper bound is $3n-3Z(n)-IZ(n) + 1$, and the existing lower bound is sharp at $n-Z(n)$ moves, where $Z(n)$ is the number of terms in the Zeckendorf decomposition of n and $IZ(n)$ is the sum of indices in the same Zeckendorf decomposition of n. We also studied four deterministic variants of the game, where there was a fixed order on which available move one takes: Combine Largest, Split Largest, Combine Smallest and Split Smallest. We prove that Combine Largest and Split Largest realize the lower bound.Split Smallest has the largest number of moves over all possible games, and is close to the new upperbound. For Combine Split games, the number of moves grows linearly with n.

Crescent Configurations in Normed Spaces
S. Miller with Sara Fish, Dylan King, Eyvi Palsson and Catherine Wahlenmayer

Integers 20, #A96, 2020.

We study the problem of crescent configurations, posed by Erd˝os in 1989. A crescent configuration is a set of n points in the plane such that: 1) no three points lie on a common line, 2) no four points lie on a common circle, 3) for each $1 \leq i \leq n-1$, there exists a distance which occurs exactly I times. Constructions of sizes $n \leq 8$ have been provided by Liu, Palásti, and Pomerance. Erdös conjectured that there exists some N for which there do not exist crescent configurations of size n for all $n \geq N$. We extend the problem of crescent configurations to general normed spaces $(R^2, \|\cdot\|)$by studying strong crescent configurations in $\|\cdot\|$. In an arbitrary norm $\|\cdot\|$, we construct a strong crescent configuration of size 4. We also construct larger strong crescent configurations of size $n \leq 6$ in the Euclidean norm and of size $n \leq 8$in the taxicab and Chebyshev norms. When defining strong crescent configurations, we introduce the notion of line-like configurations in $\|\cdot\|$. A line-like configuration in $\|\cdot\|$ is a set of points whose distance graph is isomorphic to the distance graph of equally spaced points on a line. In a broad class of norms, we construct line-like configurations of arbitrary size. Our main result is a crescent-type result about line-like configurations in the Chebyshev norm. Aline-like crescent configuration is a line-like configuration for which no three points lie on a common line and no four points lie on a common ||·|| circle. We prove that for $n \geq 7$, every line-like crescent configuration of size n in the Chebyshev norm must have a rigid structure. Specifically, it must be a perpendicular perturbation of equally spaced points on a horizontal or vertical line.

Recurrence Relations and Benford's Law

S. Miller with Madeleine Farris, Noah Luntzlara, Lily Shao and Mengxi Wang

Statistical Methods and Applications, DOI: https://doi.org/10.1007/s10260-020-00547-1, 2020.

There are now many theoretical explanations for why Benford's law of digit bias surfaces in so many diverse fields and data sets. After briefly reviewing some of these, we discuss in depth recurrence relations. As these are discrete analogues of differential equations and model a variety of real world phenomena, they provide an important source of systems to test for Benfordness. Previous work showed that fixed depth recurrences with constant coefficients are Benford modulo some technical assumptions which are usually met; we briefly review that theory and then prove some new results extending to the case of linear recurrence relations with non-constant coefficients. We prove that, for certain families of functions f and g, a sequence generated by a recurrence relation of the form $a_{n+1}=f(n)a_n+g(n)a_{n-1}$ is Benford for all initial values. The proof proceeds by parameterizing the coefficients to obtain a recurrence relation of lower degree, and then converting to a new parameter space. From there we show that for suitable choices of f and g where $f(n)$ is nondecreasing and $g(n)/f(n)^2 \to 0$ as $n \to \infty$, the main term dominates and the behavior is equivalent to equidistribution problems previously studied. We also describe the results of generalizing further to higher-degree recurrence relations and multiplicative recurrence relations with non-constant coefficients, as well as the important case when f and g are values of random variables.

An Introduction to Completeness of Positive Linear Recurrence Sequences

S. Miller with Ela Boldyriew, John Haviland, Phúc Lâm, John Lentfer, Fernando Trejos Suarez

Fibonacci Quarterly 5, 77-90, 2020.

A positive linear recurrence sequence (PLRS) is a sequence defined by a homogeneous linear recurrence relation with positive coefficients and a particular set of initial conditions. A sequence of positive integers is \emph{complete} if every positive integer is a sum of distinct terms of the sequence. One consequence of Zeckendorf's theorem is that the sequence of Fibonacci numbers is complete. Previous work has established a generalized Zeckendorf's theorem for all PLRS's. We consider PLRS's and want to classify them as complete or not. We study how completeness is affected by modifying the recurrence coefficients of a PLRS. Then, we determine in many cases which sequences generated by coefficients of the forms $[1,\dots,1,0,\dots,0,N]$ are complete. Further, we conjecture bounds for other maximal last coefficients in complete sequences in other families of PLRS's. Our primary method is applying Brown's criterion, which says that an increasing sequence $\{H_n\}^{\infty}_{n=1}$ is complete if and only if $H_1=1$ and $H_{n+1} \leq 1 + \sum^{n}_{i=1} H_i$. This paper is an introduction to the topic that is explored further in Completeness of Positive Linear Recurrence Sequences

Extending Zeckendorf's Theorem to a Non-constant Recurrence and the Zeckendorf Game on this Non-Constant Recurrence Relation

S. Miller with Ela Boldyriew, Anna Cusenza, Linglong Dai, Pei Ding, *Aidan Dunkelberg '22*, John Haviland, Kate Huffman, Dianhui Ke, Daniel Kleber, Jason Kuretski, John Lentfer, Tianhao Luo, *Clayton Mizgerd '22*, Vashisth Tiwari, Jingkai Ye, Yunhao Zhang, Xiaoyan Zheng, and Weiduo Zhu

Fibonacci Quarterly 58, No. 5, 55-76, 2020.

We generalize the Fibonacci game to a sequence defined by a non-constant recurrence relation, and analyze its properties.

Generalizing Ruth-Aaron Numbers

S. Miller with Nancy Jiang

The PUMP Journal of Undergraduate Research 4, 20-62, 2021.

A Ruth-Aaron number is such that the sum of its prime divisors, counted with multiplicity, equals the sum of the prime divisors of its successor. They have been an interest of many number theorists since the famous 1974 baseball game gave them the elegant name after two baseball stars. Many of their properties were first discussed by

Erdős and Pomerance in 1978. We generalize their results in two directions: by raising prime factors to a power and allowing a small difference between the two sums. We prove the density of power Ruth-Aaron numbers is zero (we provide a precise bound in terms of iterations and powers of logarithms), and prove similar results for almost Ruth-Aaron numbers (these are pairs of integers such that the sum of their prime powers differ by a fixed, slowly growing function). Moreover, we further the discussion of the infinitude of Ruth-Aaron numbers and provide a few possible directions for future study.

When Life Gives You Lemons, Make Mathematician

S. Miller with Kira Adaricheva, Ben Brubaker, Pat Devlin, Steven J. Miller, Vic Reiner, Alexandra Seceleanu, Adam Sheffer, and Yunus Zeytuncu

Notices of the AMS 68, No. 3, 375-478, 2021.

Optimal Transportation With Constant Strain

Frank Morgan, Wyatt Boyer, Bryan Brown, Alyssa Loving, Sarah Tammen

Involve, (12) 1-12, 2019.

My 2014 SMALL undergraduate research Geometry Group considered the currently celebrated topic of optimal transportation, but with constraint, as did Korman and McCann (2013, 2015), provided simplifications and generalizations of their examples and results, and provided some new examples and results.

On the Gonality of Cartesian Products of Graph

Ralph Morrison with Ivan Aidun

Electronic Journal of Combinatorics 27, no. 4, Paper No. 4.52, 35 pp., 2020.

In this paper we provide the first systematic treatment of Cartesian products of graphs and their divisorial gonality, which is a tropical version of the gonality of an algebraic curve defined in terms of chip-firing. We prove an upper bound on the gonality of the Cartesian product of any two graphs, and determine instances where this bound holds with equality, including for the *m x n* rook's graph with $\min\{m,n\} \leq 5$. We use our upper bound to prove that Baker's gonality conjecture holds for the Cartesian product of any two graphs with two or more vertices each, and we determine precisely which nontrivial product graphs have gonality equal to Baker's conjectural upper bound. We also extend some of our results to metric graphs.

Higher Distance Commuting Varieties

Ralph Morrison with Madeleine Elyze, Alexander Guterman, and Klemen Šivic

Linear and Multilinear Algebra, 2020.

The commuting variety of matrices over a given field is a well-studied object in linear algebra and algebraic geometry. As a set, it consists of all pairs of square matrices with entries in that field that commute with one another. In this paper, we generalize the commuting variety by using the commuting distance of matrices. We show that over an algebraically closed field, each of our sets does indeed form a variety. We compute the dimension of the distance-2 commuting variety and characterize its irreducible components. We also work over other fields, showing that the distance-2 commuting set is a variety but that the higher distance commuting sets may or may not be varieties, depending on the field and on the size of the matrices.

Gonality Sequences of Graphs

Ralph Morrison with Ivan Aidun, *Frances Dean '19, Teresa Yu '20*, and Julie Yuan

SIAM Journal of Discrete Mathematics 35, no. 2, 814-839, 2021.

We associate to any graph a sequence of integers called the gonality sequence of the graph, consisting of the minimum degrees of divisors of increasing rank on the graph. This is a tropical analogue of the gonality sequence of an algebraic curve. We study gonality sequences for graphs of low genus, proving that for genus up to 5, the gonality sequence is determined by the genus and the first gonality. We then prove that any reasonable pair of the first two gonalities is achieved by some graph. We also develop a modified version of Dhar's burning algorithm more suited for studying higher gonalities.

Use Internet Search Data to Accurately Track State-Level Influenza Epidemics

Yang, S., Ning, S., & Kou, S. C.

Scientific Report, 11, 4023, 2021.

For epidemics control and prevention, timely insights of potential hot spots are invaluable. Alternative to traditional epidemic surveillance, which often lags behind real time by weeks, big data from the Internet provide important information of the current epidemic trends. Here we present a methodology, ARGOX (Augmented Regression with Google data CROSS space), for accurate real-time tracking of state-level influenza epidemics in the United States. ARGOX combines Internet search data at the national, regional and state levels with traditional influenza surveillance data from the Centers for Disease Control and Prevention, and accounts for both the spatial correlation structure of state-level influenza activities and the evolution of people's Internet search pattern. ARGOX achieves on average 28\% error reduction over the best alternative for real-time state-level influenza estimation for 2014 to 2020. ARGOX is robust and reliable and can be potentially applied to track county- and city-level influenza activity and other infectious diseases.

Forecasting Unemployment Using Internet Search Data via PRISM

Yi, D., Ning, S., Chang, C., Kou, S.C.

Journal of the American Statistical Association, 2021.

Big data generated from the Internet offer great potential for predictive analysis. Here we focus on using online users' Internet search data to forecast unemployment initial claims weeks into the future, which provides timely insights into the direction of the economy. To this end, we present a novel method Penalized Regression with Inferred Seasonality Module (PRISM), which uses publicly available online search data from Google. PRISM is a semi-parametric method, motivated by a general state-space formulation, and employs nonparametric seasonal decomposition and penalized regression. For forecasting unemployment initial claims, PRISM outperforms all previously available methods, including forecasting during the 2008–2009 financial crisis period and near-future forecasting during the COVID-19 pandemic period, when unemployment initial claims both rose rapidly. The timely and accurate unemployment forecasts by PRISM could aid government agencies and financial institutions to assess the economic trend and make well-informed decisions, especially in the face of economic turbulence.

Accurate Regional Influenza Epidemics Tracking Using Internet Search Data

S. Ning, S. Yang, & S.C. Kou

Scientific Report 9, 5238, 2019.

Accurate, high-resolution tracking of influenza epidemics at the regional level helps public health agencies make informed and proactive decisions, especially in the face of outbreaks. Internet users' online searches offer great potential for the regional tracking of influenza. However, due to the complex data structure and reduced quality of Internet data at the regional level, few established methods provide satisfactory performance. In this article, we propose a novel method named ARGO2 (2-step Augmented Regression with GOogle data) that efficiently combines publicly available Google search data at different resolutions (national and regional) with traditional influenza surveillance data from the Centers for Disease Control and Prevention (CDC) for accurate, real-time regional tracking of influenza. ARGO2 gives very competitive performance across all US regions compared with available Internet-data-based regional influenza tracking methods, and it has achieved 30% error reduction over the best alternative method that we numerically tested for the period of March 2009 to March 2018. ARGO2 is reliable and robust, with the flexibility to incorporate additional information from other sources and resolutions, making it a powerful tool for regional influenza tracking, and potentially for tracking other social, economic, or public health events at the regional or local level.

Accurate Regional Influenza Epidemics Tracking Using Internet Search Data

H. Li, S. Ning, M. Ghandi, G. V. Kryukov, S. Gopal, A. Deik, A. Souza, K. Pierce et al.

Nature Medicine 25, 850–860, 2019.

Despite considerable efforts to identify cancer metabolic alterations that might unveil druggable vulnerabilities, systematic characterizations of metabolism as it relates to functional genomic features and associated dependencies remain uncommon. To further understand the metabolic diversity of cancer, we profiled 225 metabolites in 928 cell lines from more than 20 cancer types in the Cancer Cell Line Encyclopedia (CCLE) using liquid chromatography–mass spectrometry (LC-MS). This resource enables unbiased association analysis linking the cancer metabolome to genetic alterations, epigenetic features and gene dependencies. Additionally, by screening barcoded cell lines, we demonstrated that aberrant ASNS hypermethylation sensitizes subsets of gastric and hepatic cancers to asparaginase therapy. Finally, our analysis revealed distinct synthesis and secretion patterns of kynurenine, an immune-suppressive metabolite, in model cancer cell lines. Together, these findings and related methodology provide comprehensive resources that will help clarify the landscape of cancer metabolism.

A Comprehensive Self-Management Program with Diet Education Does Not Alter Microbiome Characteristics in Women with Irritable Bowel Syndrome

Kamp KJ, Plantinga AM, Cain K, Burr R, Barney P, Jarrett M, Luna RA, Savidge T,Shulman RJ, Heitkemper MM

Biological Research for Nursing, DOI: https://doi.org/10.1177/1099800420984543, 2021.

Background and Purpose: Changes in diet and lifestyle factors are frequently recommended for persons with irritable bowel syndrome (IBS). It is unknown whether these recommendations alter the gut microbiome and/or whether baseline microbiome predicts improvement in symptoms and quality of life following treatment. Therefore, the purpose of this study was to explore if baseline gut microbiome composition predicted response to a Comprehensive Self-Management (CSM) intervention and if the intervention resulted in a different gut microbiome composition compared to usual care.

Methods: Individuals aged 18–70 years with IBS symptoms ≥ 6 months were recruited using convenience sampling. Individuals were excluded if medication use or comorbidities would influence symptoms or microbiome. Participants completed a baseline assessment and were randomized into the eight-session CSM intervention which included dietary education and cognitive behavioral therapy versus usual care. Questionnaires included demographics, quality of life, and symptom diaries. Fecal samples were collected at baseline and 3-month post-randomization for 16S rRNA-based microbiome analysis.

Results: Within the CSM intervention group ($n = 30$), Shannon diversity, richness, and beta diversity measures at baseline did not predict benefit from the CSM intervention at 3 months, as measured by change in abdominal pain and quality of life. Based on both alpha and beta diversity, the change from baseline to follow-up microbiome bacterial taxa did not differ between CSM ($n = 25$) and usual care ($n = 25$).

Conclusions and Inferences: Baseline microbiome does not predict symptom improvement with CSM intervention. We do not find evidence that the CSM intervention influences gut microbiome diversity or composition over the course of 3 months.

Beta Diversity and Distance-Based Analysis of Microbiome Data

Plantinga AM and Wu MC, Guha S and Datta S (Ed.)

Frontiers in Probability and the Statistical Sciences, Springer Nature, Switzerland, 2021.

Distance-based analysis of microbiome beta diversity can be a powerful tool for discovering novel associations between microbial composition and a wide variety of phenotypes. Key advantages to distance-based analysis are the flexible form of association between microbiome and outcome; the potential for increased statistical power; and the ability to account for biological structure in the data (e.g., phylogenetic information). In this chapter, we begin by outlining common beta diversity metrics (distance or dissimilarity metrics). We then describe methods for data visualization, including principal coordinate analysis, and for formal hypothesis testing, including regression-based kernel association tests and sum of powered score tests. The chapter concludes with a discussion of the strengths of distance-based analysis, its limitations, and areas for future investigation.

MiRKAT: Kernel Machine Regression-Based Global Association Tests for the Microbiome

Wilson N, Zhao N, Zhan X, Koh H, Fu W, Chen J, Li H, Wu MC, Plantinga AM

Bioinformatics, btaa951, DOI: https://doi.org/10.1093/bioinformatics/btaa951, 2020.

Distance-based tests of microbiome beta diversity are an integral part of many microbiome analyses. MiRKAT enables distance-based association testing with a wide variety of outcome types, including continuous, binary, censored time-to-event, multivariate, correlated and high-dimensional outcomes. Omnibus tests allow simultaneous consideration of multiple distance and dissimilarity measures, providing higher power across a range of simulation scenarios. Two measures of effect size, a modified R-squared coefficient and a kernel RV coefficient, are incorporated to allow comparison of effect sizes across multiple kernels.

When Rooks Miss: Probability through Chess
Steven J. Miller, *Haoyu Sheng '20* and Daniel Turek

The College Mathematics Journal, 52(2): 82-93, 2021

Here we present an analysis of the maximum number of rooks which can be placed on a chess board, and how this scales with the size of the board.

W-measurable Sensitivity of Semigroup Actions
Francisc Bozgan, Anthony Sanchez, Cesar E. Silva, Jack Spielberg, David Stevens, Jane Wang

Colloquium Mathematicum, August 1, 2020

This paper studies the notion of W-measurable sensitivity in the context of countable semigroup actions. W-measurable sensitivity is a measurable generalization of sensitive dependence on initial conditions. In 2012, Grigoriev et. al. proved a classification result of conservative ergodic nonsingular dynamical systems that states all are either W-measurably sensitive or act by isometries with respect to some metric and have refined structure. We generalize this result to a class of semigroup actions. Furthermore, a counterexample is provided showing that W-measurable sensitivity is not preserved under factors. We also consider the restriction of W-measurably sensitive semigroup actions to sub-semigroups and show that the restriction remains W-measurably sensitive when the sub-semigroup is large enough (e.g. when the sub-semigroups are syndetic or thick).

Bayesian Non-Parametric Detection heterogeneity in Ecological Models
Daniel Turek, Claudia Wehrhahn and Olivier Gimenez

Environmental and Ecological Statistics, 28(2): 355-381, 2021.

We demonstrate how Bayesian non-parametric distributions can be applied in ecological models to accurately account for uncertainty in detection processes.

Efficient Estimation of Large-Scale Spatial Capture-Recapture Models
Daniel Turek, Cyril Milleret, Torbjorn Ergon, Henrik Broseth, Pierre Dupont,
Richard Bischof and Perry de Valpine

Ecosphere, 12(2): e03385, 2021.

We present techniques for efficiently fitting spatial capture-recapture models to large datasets in a Bayesian framework.

Estimating and Forecasting Spatial Population Dynamics of Apex Predators Using Transnational Genetic Monitoring
Richard Bischof, Cyril Milleret, Pierre Dupont, Joseph Chipperfield, Mahdieh Tourani, Andres Ordiz, Perry de Valpine, Daniel Turek, J. Andrew Royle, Olivier Gimenez, Oystein Flagstad, Mikael Akesson, Linn Svensson, Henrik Broseth and Jonas Kindberg

Proceedings of the National Academy of Sciences, 117(48): 30531-30538, 2020.

We perform a large-scale analysis of carnivore populations in Scandinavia.

Wild Bornean Orangutan (Pongo Pygmaeus wurmbii) Feeding Rates and the Marginal Value Theorem
DiGiorgio, A.L., Upton, E.M., Susanto, T.W. and Knott, C.D.

American Journal of Primatology, 82(10), p.e23183, 2020.

The Marginal Value Theorem (MVT) is an integral supplement to Optimal Foraging Theory (OFT) as it seeks to explain an animal's decision of when to leave a patch when food is still available. MVT predicts that a forager capable of depleting a patch, in a habitat where food is patchily distributed, will leave the patch when the intake rate within it decreases to the average intake rate for the habitat. MVT relies on the critical assumption that the feeding rate in the patch will decrease over time. We tested this assumption using feeding data from a population of wild Bornean orangutans (Pongo pygmaeus wurmbii) from Gunung Palung National Park. We hypothesized that the feeding rate within orangutan food patches would decrease over time. Data included feeding bouts from continuous focal follows between 2014 and 2016. We recorded the average feeding rate over each tertile of the bout, as well as the first, midpoint, and last feeding rates collected. We did not find evidence of a decrease between first and last feeding rates (Linear Mixed Effects Model, $n = 63$), between a mid-point and last rate (Linear Mixed Effects Model, $n = 63$), between the tertiles (Linear Mixed Effects Model, $n = 63$), nor a decrease in feeding rate overall (Linear Mixed Effects Model, $n = 146$). These findings, thus, do not support the MVT assumption of decreased patch feeding rates over time in this large generalist frugivore.

Physics

Effective field theory interactions for liquid argon target in DarkSide-50 experiment
G. K. Giovanetti and others

Physical Review D, 101, 062002, 2020

We reanalyze data collected with the DarkSide-50 experiment and recently used to set limits on the spin-independent interaction rate of weakly interacting massive particles (WIMPs) on argon nuclei with an effective field theory framework. The dataset corresponds to a total (16660 ± 270) kg- d exposure using a target of low-radioactivity argon extracted from underground sources. We obtain upper limits on the effective couplings of the 12 leading operators in the nonrelativistic systematic expansion. For each effective coupling we set constraints on WIMP-nucleon cross sections, setting upper limits between 2.4×10^{-45} cm2 and 2.3×10^{-42} cm^2 (8.9×10^{-45} cm^2 and 6.0×10^{-42} cm^2) for WIMPs of mass of 100 GeV/c^2 (1000 GeV/c^2) at 90% confidence level.

Search for double-β decay of ^{76}Ge to excited states of ^{76}Se with the MAJORANA DEMONSTRATOR
G. K. Giovanetti and others

Physical Review C, 99 (6), 2019

The MAJORANA DEMONSTRATOR is searching for neutrinoless double-beta decay in 76Ge using arrays of point-contact germanium detectors operating at the Sanford Underground Research Facility. Background results in the neutrinoless double-beta decay region of interest from data taken during construction, commissioning, and the start of full operations have been recently published. A pulse shape analysis cut applied to achieve this result, named AvsE, is described in this paper. This cut is developed to remove events whose waveforms are typical of multi-site energy deposits while retaining (90 +/- 3.5)% of single-site events. This pulse shape discrimination is based on the relationship between the maximum current and energy, and tuned using ^{228}Th calibration source data. The efficiency uncertainty accounts for variation across detectors, energy, and time, as well as for the position distribution difference between calibration and 0νββ events, established using simulations.

Search for neutrinoless double-beta decay in ^{76}Ge with 26 kg yr of exposure from the MAJORANA DEMONSTRATOR
G. K. Giovanetti and others

Physical Review C, 103, 015501, 2021

The MAJORANA DEMONSTRATOR is a neutrinoless double-β decay search consisting of a low-background modular array of high-purity germanium detectors, ~2/3 of which are enriched to 88% in ^{76}Ge. The experiment is also searching for double-beta decay of ^{76}Ge to excited states (e.s.) in ^{76}Se. ^{76}Ge can decay into three daughter states of ^{76}Se, with clear event signatures consisting of a ββ-decay followed by the prompt emission of one or two γ rays. This results with high probability in multi-detector coincidences. The granularity of the DEMONSTRATOR detector array enables powerful discrimination of this event signature from backgrounds. Using 41.9 kg yr of isotopic exposure, the DEMONSTRATOR has set world leading limits for each e.s. decay of ^{76}Ge, with 90% CL lower half-life limits in the range of (0.75–4.0)×1024 yr. In particular, for the 2ν transition to the first 0+ e.s. of ^{76}Se, a lower half-life limit of 7.5×10^{23} yr at 90% CL was achieved.

SiPM-matrix readout of two-phase argon detectors using electroluminescence in the visible and near infrared range
G. K. Giovanetti and others

Eur. Phys. J. C, 81:153 2021

Proportional electroluminescence (EL) in noble gases is used in two-phase detectors for dark matter searches to record (in the gas phase) the ionization signal induced by particle scattering in the liquid phase. The “standard” EL mechanism is considered to be due to noble gas excimer emission in the vacuum ultraviolet (VUV). In addition, there are two alternative mechanisms, producing light in the visible and near infrared (NIR) ranges. The first is due to bremsstrahlung of electrons scattered on neutral atoms (“neutral bremsstrahlung”, NBrS). The second, responsible for electron avalanche scintillation in the NIR at higher electric fields, is due to transitions between excited atomic states. In this work, we have for the first time demonstrated two alternative techniques of the optical readout of two-phase argon detectors, in the visible and NIR range, using a silicon photomultiplier matrix and electroluminescence due to either neutral bremsstrahlung or avalanche scintillation. The amplitude yield and position resolution were measured for these readout techniques, which allowed to assess the detection threshold for electron and nuclear recoils in two-phase argon detectors for dark matter searches. To the best of our knowledge, this is the first practical application of the NBrS effect in detection science.

ADC Nonlinearity Correction for the MAJORANA DEMONSTRATOR

G. K. Giovanetti and others

IEE Trans. Nucl. Sci, 10. 1109, 2020

Imperfections in analog-to-digital conversion (ADC) cannot be ignored when signal digitization requirements demand both wide dynamic range and high resolution, as is the case for the MAJORANA DEMONSTRATOR ^{76}Ge neutrinoless double-beta decay search. Enabling the experiment's high-resolution spectral analysis and efficient pulse shape discrimination required careful measurement and correction of ADC nonlinearities. A simple measurement protocol was developed that did not require sophisticated equipment or lengthy data-taking campaigns. A slope-dependent hysteresis was observed and characterized. A correction applied to digitized waveforms prior to signal processing reduced the differential and integral nonlinearities by an order of magnitude, eliminating these as dominant contributions to the systematic energy uncertainty at the double-beta decay Q value.

Viscoelastic and poroelastic relaxations of soft solid surfaces

Q. Xu, L.A. Wilen, K.E. Jensen, R.W. Style, E.R. Dufresne

Physical Review Letters 125, 238002, 2020

Understanding surface mechanics of soft solids, such as soft polymeric gels, is crucial in many engineering processes, such as dynamic wetting and adhesive failure. In these situations, a combination of capillary and elastic forces drives the motion, which is balanced by dissipative mechanisms to determine the rate. While shear rheology (i.e., viscoelasticity) has long been assumed to dominate the dissipation, recent works have suggested that compressibility effects (i.e., poroelasticity) could play roles in swollen networks. We use fast interferometric imaging to quantify the relaxation of surface deformations due to a displaced contact line. By systematically measuring the profiles at different time and length scales, we experimentally observe a crossover from viscoelastic to poroelastic surface relaxations.

Two-beam coupling in the production of quantum correlated images by four-wave mixing

Kevin Jones and others

Optics Express 29 (11), 16665-16675, 2021

We investigate the effect of 2-beam coupling in different imaging geometries in generating intensity-difference squeezing from four-wave mixing (4WM) in Rb atomic vapors. A recently introduced dual-seeding technique can cancel out the classical noise in a seeded four- wave mixing process. This dual-seeding technique, however, can introduce new complications that involve 2-beam coupling between different seeded spatial modes in the atomic vapor and can ruin squeezing at frequencies on the order of the atomic linewidth and below. This complicates some forms of quantum imaging using these systems. Here we show that seeding the 4WM process with skew rays can eliminate the excess noise caused by 2-beam coupling. To avoid 2-beam coupling in bright, seeded images, it is important to re-image the object in the gain medium, instead of focusing through it.

Wall speed and shape in singlet-assisted strong electroweak phase transitions

Avi Friedlander, *Ian Banta '20*, James M. Cline, and David Tucker-Smith

Phys. Rev. D 103, 5, 055020 (2021)

Models with singlet fields coupling to the Higgs can enable a strongly first-order electroweak phase transition, of interest for baryogenesis and gravity waves. We improve on previous attempts to self-consistently solve for the bubble wall properties—wall speed and shape—in a highly predictive class of models with Z2-symmetric singlet potentials. A new algorithm is implemented to determine wall speeds and profiles throughout the singlet parameter space in the case of subsonic walls, focusing on models with strong enough phase transitions to satisfy the sphaleron washout constraint for electroweak baryogenesis. We find speeds as low as 0.1c in our scan over parameter space, and the singlet must be relatively light to have a subsonic wall, with a mass below approximately 135 GeV.

Baryogenesis and gravity waves from a UV-completed electroweak phase transition

Benoit Laurent, James M. Cline, Avi Friedlander, Dong-Ming He, Kimmo Kainulainen, and David Tucker-Smith

Phys. Rev. D 103, 12, 123529 (2021)

We study gravity wave production and baryogenesis at the electroweak phase transition in a real singlet scalar extension of the Standard Model, including vectorlike top partners, to generate the CP violation needed for electroweak baryogenesis (EWBG). The singlet makes the phase transition strongly first order through its coupling to the Higgs boson, and it spontaneously breaks CP invariance through a dimension-five contribution to the top quark mass term, generated by integrating out the heavy top quark partners. We improve on previous studies by incorporating updated transport equations, compatible with large bubble wall velocities. The wall speed and thickness are computed directly from the microphysical parameters rather than treating them as free parameters, allowing for a first-principles computation of the baryon asymmetry. The size of the CP-violating dimension-five operator needed for EWBG is constrained by collider, electroweak precision, and renormalization group running constraints. We identify regions of parameter space that can produce the observed baryon asymmetry or observable gravitational wave (GW) signals. Contrary to standard lore, we find that for strong deflagrations, the efficiencies of large baryon asymmetry production and strong GW signals can be positively correlated. However, we find the overall likelihood of observably large GW signals to be smaller than estimated in previous studies. In particular, only detonation-type transitions are predicted to produce observably large gravitational waves.

Transition probabilities and transition rates in discrete phase space

William F. Braasch, Jr. and William K. Wootters

Phys. Rev. A 102, 052204 (2020)

The evolution of the discrete Wigner function is formally similar to a probabilistic process, but the transition probabilities, like the discrete Wigner function itself, can be negative. We investigate these transition probabilities, as well as the transition rates for a continuous process, aiming particularly to give simple criteria for deciding when a set of such quantities corresponds to a legitimate quantum process. We also show how the transition rates for any Hamiltonian evolution can be worked out by expanding the Hamiltonian as a linear combination of displacement operators in the discrete phase space.

Psychology Abstracts

Feeding Experimentation Device Version 3 (FED3): An Open-Source Device for Measuring Food Intake and Operant Behavior in Rodents

B.A. Matikainen-Ankney, T. Earnest, M. Ali, E. Casey, J.G. Wang, A.K. Sutton, A.A. Legaria, K.M. Barclay, L.B. Murdaugh, M.R. Norris, Y. Chang, K.P. Nguyen, E. Lin, A. Reichenbach, R.E. Clarke, R. Stark, S.M. Conway, F. Carvalho, R. Al-Hasani, J.G. McCall, M.C. Creed, V.A. Cazares, M.W. Buczynski, M.J. Krashes, Z.B. Andrews, A.V. Kravitz

eLife, DOI: 10.7554/eLife.66173, 2021.

Feeding is critical for survival, and disruption in the mechanisms that govern food intake underlies disorders such as obesity and anorexia nervosa. It is important to understand both food intake and food motivation to reveal mechanisms underlying feeding disorders. Operant behavioral testing can be used to measure the motivational component to feeding, but most food intake monitoring systems do not measure operant behavior. Here, we present a new solution for monitoring both food intake and motivation in rodent home-cages: the Feeding Experimentation Device version 3 (FED3). FED3 measures food intake and operant behavior in rodent home-cages, enabling longitudinal studies of feeding behavior with minimal experimenter intervention. It has a programmable output for synchronizing behavior with optogenetic stimulation or neural recordings. Finally, FED3 design files are open-source and freely available, allowing researchers to modify FED3 to suit their needs.

Neurobiology of Stress

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Acute physical or psychological stress can elicit adaptive behaviors that allow an organism maintain homeostasis. However, intense and/or prolonged stressors often have the opposite effect, resulting in maladaptive behaviors and curbing goal-directed action; in the extreme, this may contribute to the development of psychiatric conditions like generalized anxiety disorder, major depressive disorder, or post-traumatic stress disorder. While treatment of these disorders generally focuses on reducing reactivity to potentially threatening stimuli, there are in fact impairments across multiple domains including valence, arousal, and cognition. Here, we use the genetically stress-susceptible 129S1 mouse strain to explore the effects of stress across multiple domains. We find that 129S1 mice exhibit a potentiated neuroendocrine response across many environments and paradigms, and that this is associated with reduced exploration, neophobia, decreased novelty- and reward-seeking, and spatial learning and memory impairments. Taken together, our results suggest that the 129S1 strain may provide a useful model for elucidating mechanisms underlying myriad aspects of stress-linked psychiatric disorders as well as potential treatments that may ameliorate symptoms.

Nationality Dominates Gender in Decision-Making in the Dictator and Prisoner's Dilemma Games

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Across a variety of contexts, adults tend to cooperate more with ingroup members than outgroup members. However, humans belong to multiple social groups simultaneously and we know little about how this cross-categorization affects cooperative decision-making. Nationality and gender are two social categories that are ripe for exploration in this regard: They regularly intersect in the real world and we know that each affects cooperation in isolation. Here we explore two hypotheses concerning the effects of cross-categorization on cooperative decision-making. First, the additivity hypothesis (H1), which proposes that the effects of social categories are additive, suggesting that people will be most likely to cooperate with partners who are nationality and gender ingroup members. Second, the category dominance hypothesis (H2), which proposes that one category will outcompete the other in driving decision-making, suggesting that either nationality or gender information will be privileged in cooperative contexts. Secondarily, we test whether identification with—and implicit bias toward—nationality and gender categories predict decision-making. Indian and US Americans (N = 479), made decisions in two cooperative contexts—the Dictator and Prisoner's Dilemma Games—when paired with partners of all four social categories: Indian women and men, and US American women and men. Nationality exerted a stronger influence than gender: people shared and cooperated more with own-nationality partners and believed that own-nationality partners would be more cooperative. Both identification with—and implicit preferences for—own-nationality, led to more sharing in the Dictator Game. Our findings are most consistent with H2, suggesting that when presented simultaneously, nationality, but not gender, exerts an important influence on cooperative decision-making. Our study highlights the importance of testing cooperation in more realistic intergroup contexts, ones in which multiple social categories are in play.

Of Two Minds: A Registered Replication

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OSF, osf.io/8m3xb, September 2021.

Several dual-process theories of evaluative learning posit two distinct implicit (or automatic) and explicit (or controlled) evaluative learning processes. As such, one may like a person explicitly but simultaneously dislike them implicitly. Dissociations between direct measures (e.g., Likert scales), reflecting explicit evaluations, and indirect measures (e.g., Implicit Association Test), reflecting implicit evaluations, support this claim. Rydell et al. (2006) found a striking dissociation when they brief flashed either positive or negative words prior to presenting a photograph of a person was with behavioral information of the opposite valence was presented: IAT scores reflected the valence of the flashed words whereas rating scores reflected the opposite valence of the behavioral information. A recent study, however, suggests that this finding may not be replicable. Given its theoretical importance, we report two new replication attempts (n = 153 recruited in Belgium, Germany and the USA; n = TBD recruited in Hong Kong and the USA).

The Role of Intentionality in Social Priming

M. J. Ferguson & J. Cone

Psychological Inquiry, 32(1), 38–40. https://doi.org/10.1080/1047840X.2021.1889839, 2020.

Comments on an article by Jeffrey W. Sherman & Andrew M. Rivers (see record 2021-33635-001). In their target article on the possible causal role of the term "social priming" in the reputational crisis surrounding social psychology, Sherman and Rivers should be commended for their work laying out the conceptual messiness of the term. In particular, the authors agree that the adjective "social" is definitionally intractable in at least two ways. First, the manner in which it has been used does not capture priming research that seems just as social as the studies deemed problematic. But, secondly, even casting aside contemporary scrutiny of priming research, the author also agrees that pinpointing the boundaries of the term "social" is fraught. In conclusion, the authors are in broad agreement with Sherman and Rivers on the need for greater conceptual clarity of the terms used to characterize whole areas of research and the increased adoption of more computational modeling methods to complement verbal theories of priming. However, they argue for the importance of understanding the role of the purported features of the psychology behind priming that led to the original work in the first place: awareness, intention, control, and efficiency.

Family nurture intervention in the NICU increases autonomic regulation in mothers and children at 4-5 years of age: Follow-up results from a randomized controlled trial

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Background: Maturation of multiple neurobehavioral systems, including autonomic regulation, is altered by preterm birth. The purpose of this study was to determine the long-term effects of Family Nurture Intervention (FNI) in the NICU on autonomic regulation of preterm infants and their mothers.

Method: A subset of infants and mothers (48% of infants, 51% of mothers) randomly assigned to either standard are (SC), or SC plus the FNI in the NICU in a prior RCT (ClincalTrials.gov; NCT01439269) returned for follow-up assessments when the children were 4 to 5 years corrected age (CA). ECGs were collected for 10 minutes in mothers and their children while children were in their mothers' laps. Heart rate, standard deviation for heart rate, respiratory sinus arrhythmia (RSA)-an index of parasympathetic regulation, and a measure of vagal efficiency were quantified.

Results: Both children and mothers in the FNI group had significantly greater levels of RSA compared to the SC group (child: mean difference = 0.60, 95% CI 0.17 to 1.03, $p = 0.008$; mother: mean difference = 0.64, 95% CI 0.07 to 1.21, $p = 0.031$). In addition, RSA increased more rapidly in FNI children between infancy and the 4 to 5-year follow-up time point (SC = +3.11±0.16 loge msec2, +3.67±0.19 loge msec2 for FNI, $p<0.05$). These results show that the rate of increase in RSA from infancy to childhood is more rapid in FNI subjects.

Conclusion: Although these preliminary follow-up results are based on approximately half of subjects originally enrolled in the RCT, they suggest that FNI-NICU led to healthier autonomic regulation in both mother and child, when measured during a brief face-to-face socioemotional interaction. A Pavlovian autonomic co-conditioning mechanism may underly these findings that can be exploited therapeutically. Out of the Box: Forging a Career in Clinical Psychology in the Liberal Arts Academy

L. Heatherington (Invited Chapter, no abstract)

In N. Newton and J. Bookwala (Eds), Reflections from Pioneering Women in Psychology. NY: Cambridge University Press, in press.

Systemic and conjoint couple and family therapies: Recent advances and future promise

M.L. Friedlander, L. Heatherington & G.M. Diamond (Invited Chapter, no abstract)

In M. Barkham, W. Lutz, and L. Castonguay (Eds.), Bergin and Garfield's Handbook of Psychotherapy and Behavior Change (7th ed.), in press.

Disordered Eating- and Exercise-Related Behaviors and Cognitions During the First-Year College Transition

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Journal of American College Health, 1-16, 2020.

The transition to college marks significant changes in an adolescent's vulnerability to disordered eating, and the college environment may influence eating- and exercise-related thoughts and behaviors in complex ways. This study investigated changes over time in disordered eating-related and exercise-related cognitions and behaviors in students entering college, as related to four key individual difference variables: conditions of self-worth, gender, parent education, participation in college athletics. The transition to college was accompanied by changes in disordered exercise-related cognitions and exercise frequency, but no significant changes in disordered eating-related outcomes. Athletic participation was protective against nearly all disordered eating- and exercise-related cognitions and behaviors. Basing self-worth on appearance and others' approval played a meaningful but nuanced role as a risk factor. The findings revealed that gender was not a strong or consistent factor in eating disorder-related symptoms; thus, men should not be overlooked when assessing for subclinical eating disorder risk during college transition. Risk assessment and preventive interventions should also consider students' athletic participation and relevant conditions of self-worth.

Answering a Factual Question Today Increases One's Confidence in the Same Answer Tomorrow—Independent of Fluency.

J. L. Fiechter & N. Kornell

Psychonomic Bulletin & Review, https://doi.org/10.3758/s13423-021-01882-4, 2021.

We investigated the cognitive processes that cause confidence to increase. Participants were asked 48 general-knowledge questions either once or three times, without feedback. After 2 min (Experiment 1) or 48 h (Experiment 2) they were asked the same questions again, and rated their confidence. Repeated questioning increased confidence but not accuracy. This increase, which replicated research on episodic memory in the eyewitness literature (e.g., Shaw, Journal of Experimental Psychology: Applied 2: 126–146, 1996), occurred even though accuracy was only around 25%. A mediation analysis identified response repetition, but not fluency, as a mechanism underlying growth in confidence. Thus, the basis for confidence judgments appears to be whether one's current response has been generated previously. In sum, answering a factual question increases confidence, but not accuracy, and this happens because learners use response repetition as a cue for confidence judgments.

How the Wisdom of Crowds, and of the Crowd Within, are Affected by Expertise
J. L. Fiechter & N. Kornell

Cognitive Research: Principles and Implications, 6, 1-7, https://doi.org/10.1186/s41235-021-00273-6, 2021.

We investigated the effect of expertise on the wisdom of crowds. Participants completed 60 trials of a numerical estimation task, during which they saw 50–100 asterisks and were asked to estimate how many stars they had just seen. Experiment 1 established that both inner- and outer-crowd wisdom extended to our novel task: Single responses alone were less accurate than responses aggregated across a single participant (showing inner-crowd wisdom) and responses aggregated across different participants were even more accurate (showing outer-crowd wisdom). In Experiment 2, prior to beginning the critical trials, participants did 12 practice trials with feedback, which greatly increased their accuracy. There was a benefit of outer-crowd wisdom relative to a single estimate. There was no inner-crowd wisdom effect, however; with high accuracy came highly restricted variance, and aggregating insufficiently varying responses is not beneficial. Our data suggest that experts give almost the same answer every time they are asked and so they should consult the outer crowd rather than solicit multiple estimates from themselves.

Why and How You Should Read Student Evaluations of Teaching
N. Kornell

Journal of Applied Research in Memory and Cognition, 9, 165–169, https://doi.org/10.1016/j.jarmac.2020.02.006, 2020.

If you think student evaluations of teaching (SET) tell you how much students learn from a teacher, get used to disappointment. SET scores are not correlated with learning (Uttl, White, & Gonzalez, 2017), they can create perverse incentives for teachers, and they are biased (Carpenter, Witherby, & Tauber, 2020). Criticisms like these have led some to suggest that SET should be abandoned. I argue that they should not. SET are biased, but most of this bias comes from the students, so there is no unbiased alternative. They do create bad incentives, but they create good incentives as well. Most important, SET measure student opinion. Knowing what the students think is not as good as knowing how good a teacher is, but student opinion does matter. SET are easy to misread, but useful if one knows how to use them. As Mike Tyson said, “It’s good to know how to read, but it’s dangerous to know how to read and not how to interpret what you’re reading.” Why should you listen to me? I am a professor of cognitive psychology at Williams College, a liberal arts college that prides itself on good teaching. I recently helped design a new SET form for Williams and I have written about SET before (Kornell & Hausman, 2016). Also, defending SET goes against my own bias: I hate SET. My first year at Williams College, I was shattered by my low ratings. Ten years later, my ratings are average, but like a rat that has been shocked repeatedly, I still freeze when I think about students judging me.

Sleep and Suicide: A Systematic Review and Meta-Analysis of Longitudinal Studies
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Clinical Psychology Review, 81, Epub, https://doi.org/10.1016/j.cpr.2020.101895, 2020.

The current review provides a quantitative synthesis of the empirical literature on sleep disturbance as a risk factor for suicidal thoughts and behaviors (STBs). A systematic search of PsycINFO, MEDLINE, and the references of prior reviews resulted in 41 eligible studies included in this meta-analysis. Sleep disturbance, including insomnia, prospectively predicted STBs, yielding small-to-medium to medium effect sizes for these associations. Complicating interpretation of these findings however, is that few studies of suicidal ideation and suicide attempts, as well as none of suicide deaths, assessed short-term risk (i.e., employed follow-up assessments of under a month). Such studies are needed to evaluate current conceptualizations of sleep dysregulation as being involved in acute risk for suicidal behavior. This want of short-term risk studies also suggests that current clinical recommendations to monitor sleep as a potential warning sign of suicide risk has a relatively modest empirical basis, being largely driven by cross-sectional or retrospective research. The current review ends with recommendations for generating future research on short-term risk and greater differentiation between acute and chronic aspects of sleep disturbance, and by providing a model of how sleep disturbance may confer risk for STBs through neuroinflammatory and stress processes and associated impairments in executive control.

Dopaminergic Genetic Variation in Young Adolescents: Associations with Sensation-Seeking

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Deficient reward functioning, including reward-related personality, is implicated in depression's etiology. A dopaminergic genetic multilocus genetic profile score (MGPS) has previously been associated with neural reward responsivity but, despite theoretical basis, has not been studied with reward-related personality. Such research is needed to elucidate associations between genetic variation and reward-related personality in a developmentally sensitive population. In the present study, we examined associations between dopaminergic MGPS's and self-report reward-related personality in two young adolescent samples aged 10-15 years old (Sample 1: N = 100 girls, 82% White, 18% Other; Sample 2: N = 141, 65 girls, 76 boys, 89.36% White, 10.64% Other) using an established MGPS and an augmented MGPS. A "mini" meta-analysis synthesized results across samples. In Sample 1, an exploratory mediation analysis intended to gauge effect size for future work tested a path between the MGPS and depression through significant reward traits. In each independent sample, both MGPS's showed significant associations with sensation-seeking but not social drive, a pattern that persisted following correction. Effect sizes of novel variants were at least as robust as established variants, suggesting their added utility. Additionally, the exploratory mediation analysis suggested no noteworthy indirect effect, but a small ($R2 = 0.022$), statistically non-significant direct effect of the MGPS predicting prospective depressive symptoms. Results suggest that dopaminergic genetic variation is associated with the reward-related personality trait of sensation seeking but not social drive. Additional work is needed to probe whether sensation seeking may be a path through which this genetic variation confers depression risk.