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Perspectives in Research

by Dr. Ashfeld

Like many, my first true exposure to research was when I joined a lab as an undergraduate, which, if I remember correctly, was during my sophomore year after taking my first semester of organic chemistry. I distinctly recall the frustration I felt as I worked through my first research project, which dealt with the structural elucidation of natural products using nuclear magnetic resonance (NMR) imaging experiments. The idea was relatively straightforward in that I was tasked with the synthesis of a small molecule that when appended to an unresolved natural product, the NMR spectra obtained would provide valuable insight into their molecular architecture and 3-dimensional structure. Knowing the absolute structure of these naturally derived compounds is particularly important due to their intriguing biological properties that render them interesting therapeutic candidates in drug discovery campaigns. As I think back on that project now, I would in no way consider the synthetic plan as particularly arduous or challenging, but that didn't stop me from struggling mightily in getting even the simplest of transformations to work the way we felt they should. The corollary to those relative difficulties that present themselves when wading into unexplored areas of chemistry is that when the experiments finally do work as designed, the exhilaration is incredible. What I wasn't aware of at the time was that these undergraduate research years of mine were quite formative in that were my first in a long line of frustrations and rejections that academic research had in store. However, those periods of exaltation when something you have labored at for quite some time finally does work, and you have that rare opportunity to observe something that no one else has seen before, is not only a unique experience, but also serves to get you through the days, weeks, or sometimes even months when it feels like no progress is made.

Following this initial undergraduate exposure to challenges and hurdles that characterize academic research, I quickly discovered that this seemed a pervasive theme across my graduate, postdoctoral, and independent research endeavors. Oddly enough, sometimes successes can even masquerade as failures. I recall a particularly unusual result as a graduate student in the lab when I noticed a selectivity trend in the reaction I was examining. Because it was not what I was expecting, my initial conclusion was that this line of study was not going to take us where we needed to go en route to our ultimate target. My graduate advisor saw those results in a drastically different light, and that collection of results ultimately came to compromise the majority of my Ph.D. thesis. At the time I thought that exchange I had with my advisor about the value of these results as particularly unusual. However, since embarking on my independent career, I have realized that recognizing the successes in the apparent failures is actually a significant part of my responsibility as a research advisor.

Although it did take me some time to recognize the value of those early lessons, they have stuck with me to this day. While I do not get to spend as much time in the laboratory conducting experiments as I would like anymore, it is not as if those disappointments have disappeared. I live vicariously through the successes and failures of those students I am lucky enough to work with in our research group. However, now I also get to experience the acceptances and rejections of manuscripts we submit for publication and funding applications to support our research efforts far more vividly than I ever did as an undergraduate, graduate or postdoctoral researcher. One piece of advice that I received from a senior colleague of mine, now emeritus Professor Marvin J. Miller, when I joined the faculty at Notre Dame almost 18 years ago now has stuck with me to this day. I am going to paraphrase what he told me because I simply cannot recall the exact phrasing he used, but he reminded me that it was perfectly acceptable, almost expected really, to get frustrated and disappointed when experiments, manuscript reviews, and grant applications did not go your way, but we should never get discouraged. As long as you have faith in your ideas and do the work necessary to bring them to fruition, then the results will eventually come. What he did not tell me at the time was that when success finally does come, it is infinitely more enjoyable as a result of the challenges that had to be overcome in order to get there. This is advice I share all my students, whether they be in the classroom or laboratory, and especially my own kids as they navigate their own school and athletic pursuits. We should never be content with failure. It is supposed to be unpleasant, but it should always provide a learning opportunity that will inevitably make our future endeavors successful and perhaps most importantly, that much more enjoyable.

- Dr. Brandon Ashfeld, Professor in the Department of Chemistry & Biochemistry

Letter from the Editors

Since its founding in 2009, *Scientia* has been vital in fostering scientific research within the Notre Dame community. As a student-run organization, *Scientia* provides a platform for undergraduates to publish their research, highlights the groundbreaking work of students and faculty, and advocates for students to refine their scientific writing and editing skills. By engaging with the journal, the Notre Dame community not only shares valuable knowledge but also gains insight into the wide array of research happening across campus.

During our time as Editors in Chief, we have been honored to continue to expand this mission. *Scientia* has proudly offered assistance to undergraduate student researchers in financial need through its Charles Edison Foundation Fellowships. This year, with the support of the University of Notre Dame College of Science, we have doubled the funding going to students through this program. We are proud to have hosted six successful Talk Science events throughout the 2024-2025 academic year, which spotlighted a wide variety of research from students and faculty studying biology, environmental science, chemistry, biochemistry, neuroscience, mathematics, physics, and astronomy.

Volume 6 of *Scientia* marks 16 years of dedicated work highlighting the contributions of student researchers and the impressive scientific advancements made by the Notre Dame community. From documenting waterborne pathogen populations in Belize to understanding consciousness-related brain processes, this volume highlights the remarkable work being done on campus. We hope that this publication sparks curiosity and deepens enthusiasm for the exciting research unfolding at Notre Dame. Through collaboration, inclusion, and a shared intellectual drive, we can continue making meaningful contributions to the scientific world.

This journal was only made possible by the hard work of our dedicated *Scientia* team. We extend our deepest gratitude to our outstanding Editorial Board for their passion and hard work in promoting scientific research at Notre Dame. A special thanks goes to Noelle Dorvault, our Chief-of-Staff, whose exceptional planning, organization, and outreach have been instrumental in the success of our Talk Science events. We are also sincerely grateful to our advisor, Dr. Xuemin Lu, for her unwavering mentorship and support. As this academic year comes to a close, we are excited to pass the roles of Editors in Chief to William Pater and Charlie Desnoyers, and Chief of Staff to James Lazar. We are fully confident in their ability to continue *Scientia*'s legacy in the 2025-2026 academic year and look forward to witnessing the journal's future achievements.

In Notre Dame,
Andrew Dinh and Joshua Moeller
Editors-in-Chief

Editorial Board

Thinking It Through: The Adams Lab's New Ways of Looking at the Brain

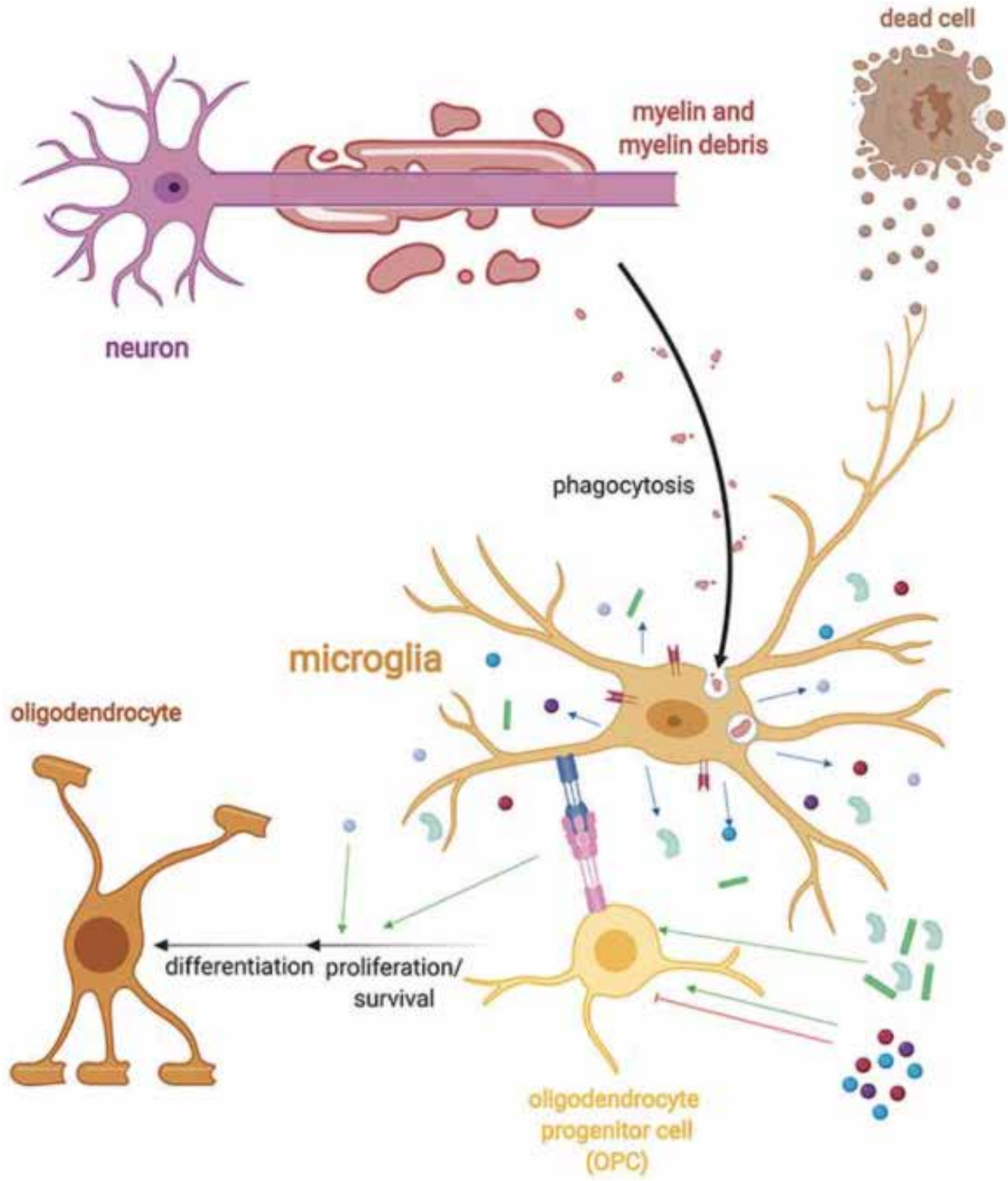
by Mark Bausch '28

Research at the University of Notre Dame comes in many shapes and forms. From more qualitative studies focused on statistical analyses to classic benchwork, the primary investigators of Our Lady's University excel in all aspects of improving the world by their work. One lab that is an exemplar of Notre Dame's mission is a relatively new lab in the Department of Biological Sciences headed by Dr. Katrina Adams. The lab primarily focuses on investigating how diseases such as multiple sclerosis (MS), impact the brain. Diseases like MS are called demyelinating diseases because they destroy or damage myelin, which is a fatty insulating layer that sheaths nerves in the central nervous system, allowing for efficient and effective transmission of electrical signals throughout the body. Damage to myelin slows these impulses, leading to a range of neurological and motor symptoms. The lab's work is incredibly important. Despite MS's status as one of the leading causes of chronic neurological disorder, there is no cure or treatment for progressive MS. Thus, the researchers in the Adams Lab hope to uncover more knowledge regarding regenerative processes that repair the brain post-injury in order to provide treatments in the future.

Central to the lab's work is investigating the regenerative potential of different neural stem and progenitor cells found in the brain after such diseases. As seen in the image, a demyelinating injury causes the release of myelin debris, which in turn triggers activation of nearby glial cells (microglia and astrocytes). These reactive glia clear the debris through phagocytosis and secrete factors that recruit progenitors of myelinating cells like oligodendrocytes. The oligodendrocyte progenitor cells (OPCs) eventually differentiate into mature oligodendrocytes that generate new myelin and prevent neuronal loss. In addition, during demyelination, endogenous neural stem cells in the brain can also differentiate into new oligodendrocytes. Adult neural stem cells have primarily been studied for their ability to create new neurons, or adult neurogenesis. How neural stem cells produce new glial cells, a process known as gliogenesis, is still a mystery. In addition, how microglia and astrocytes recruit these progenitor cells remains unknown. The Adams Lab's research is focused on these exciting questions. Increasing production of new mature oligodendrocytes could provide an avenue to regenerative treatments, and potential cures, for MS.

The lab simulates these injuries in murine models through both global injuries that demyelinate much of the brain and direct injuries that target specific areas of the white matter. The activity of OPCs and neural stem cells is followed at different days post-injury using cellular markers like Ki-67 and BrdU, along with lineage tracing and gene expression analyses. The major eventual goal is to understand the dynamics of progenitor response in the immediate and long-term resolutions of demyelination in order to better understand the pathogenesis of MS and provide treatments for affected populations.

All of the lab's efforts are spearheaded by Dr. Adams, whose strong background in neurodevelopmental and regenerative neurological research allow for great progress towards answering these questions. After earning her BS in biochemistry and cell biology from the University of California San Diego in 2008 and PhD in molecular biology from the University of California Los Angeles in 2014, she completed a seven-year fellowship at the Children's Research Institute at Children's National Hospital in Washington, DC. Based within the Institute's Center for Neuroscience Research, she focused on promoting recovery after developmental brain injuries. Though Dr. Adams' undertakings at Notre Dame are currently more concerned with adult injury, her background gives her lab a unique and important lens on its quest to understand demyelinating pathologies and eventually ameliorate such disorders.



An overview of the processes activated by a demyelinating injury.

Indeed, the University of Notre Dame is dedicated to advancing the common good. All of its labs are focused on problems that are prevalent in many individuals' lives. Given the huge and understated impact of MS, the Adams Lab is at the vanguard of the University's ideals.

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Notre Dame-MD Anderson Research Partnership for Undergraduates

by Sisy Chen '25

This past summer, five Notre Dame students had the unique opportunity to participate in a prestigious research experience at the MD Anderson Cancer Center in Houston, Texas. As one of the nation's top cancer care research centers and hospitals, MD Anderson is at the forefront of groundbreaking discoveries in cancer treatment, prevention, and patient care. The ten-week program allows students to gain invaluable hands-on laboratory experience, engage in mentorship with distinguished faculty members, and develop a deeper understanding of the scientific and medical fields.

Among this summer's participants was current senior Mae Wang, who shared her reflections on her transformative experience at MD Anderson. Wang worked under the mentorship of Dr. Hui Zhao, focusing her research on prostate cancer incidence and survival trends in the United States. Utilizing statistical methods and data analysis, Wang contributed to important insights into the factors that affect patient outcomes. Through her research, she deepened her understanding of epidemiological patterns in cancer while refining her analytical and problem-solving skills.

One of the most impactful aspects of Wang's summer at MD Anderson was the opportunity to engage with the larger scientific and medical community. She described the MD Anderson environment as incredibly supportive, with a strong sense of collaboration and mentorship. "It was a place where you could interact with faculty really easily but also see the patients in the facility as well," Wang shared. Witnessing how laboratory research translated into tangible benefits for patients reinforced her passion for cancer biology and drug discovery.

Sophomore Gaaya Binoj also had a transformative summer working in the Mok Lab in the Department of Gynecologic Oncology and Reproductive Medicine under the mentorship of Dr. Chi Lam Au Yeung. Her research focused on investigating the role of obesity in endometrial cancer, which has the strongest association with obesity among the twenty most frequent tumor types. Specifically, her team studied the role of ITLN1, an adipokine, on the proliferation and motility of endometrioid endometrial cancer cells. Their research found that ITLN1 significantly suppressed cancer cell growth and migration, suggesting that ITLN1 may have the potential to serve as a biomarker or therapeutic target in the future.

Binoj also emphasized the excitement of being surrounded by leading scientists at the Texas Medical Center. "I got to meet a lot of great people! Also, ND alumni at MDACC and other hospitals were gracious enough to let me shadow them, and those experiences were very eye-opening," she said. Her time at MD Anderson solidified her aspirations to attend medical school, as she was deeply inspired by the physician-scientists she met who are making a significant impact through both their clinical practice and research.

Beyond the lab, the students had the chance to attend seminars, participate in professional development workshops, and network with leading scientists in the field. The program also provided insight into various career paths within cancer research, from academia to pharmaceutical development and clinical applications. These experiences have proven to be instrumental in shaping the participants' future career aspirations.

For Wang and Binoj, the summer research program was more than just a learning opportunity—it was a defining moment in their academic and professional journeys. As she prepares for graduation, Wang is planning to pursue a PhD in biomedical sciences. Binoj would like to attend medical school, inspired by the impactful work of physician-scientists at MD Anderson. By fostering a collaborative and immersive environment, the ND-MD Anderson program continues to empower Notre Dame students with the skills, experience, and passion necessary to make a lasting difference in the fields of medicine and cancer research.

Kate the Chemist Joins Notre Dame

by Charles Sander '27

The University of Notre Dame's College of Science has created a new faculty position: Professor for the Public Understanding of Science. The role of this professor is to enhance the college's visibility on the national and international level. Chemist, professor, podcast host, author, and performer Kate Biberdorf, popularly known as "Kate the Chemist," became the first to hold this position as of September 2024. Biberdorf has made it her mission to "show a different version of a scientist" by making science fun and accessible to everyone, whether that means performing events at public schools, appearing on national television, or writing books that bring complex scientific concepts to life.

Biberdorf has been a science performer for several years as a professor at the University of Texas at Austin, but she sees her new position, which is the first of its kind in the United States, as a platform to take the important work scientists are doing and make it accessible to others. Her goal is not to convince people what to believe about science, but rather to give people the ability to further understand science and come to their own conclusions.

Furthermore, Biberdorf believes that art is foundational to her work both as a performer and a scientist. She believes emotional responses to science—whether that means watching a burst of green flames or exploding paint cans—are a powerful way to engage people. By incorporating elements of theater, audience engagement, and storytelling into her demonstrations, she hopes to challenge traditional stereotypes of scientists and inspire more individuals to engage with STEM.

As part of her five-year contract with the University, Biberdorf will be creating content in a unique part-lab and part-studio makerspace. She will collaborate with other Notre Dame faculty, inviting them to conduct experiments and share their research. At the same time, she'll keep working to make science exciting and accessible to the public—appearing on TV, giving lectures across the country and and the globe, writing books, hosting podcasts, and producing online content. While Kate the Chemist has already gone viral on various social media platforms, including a video with footage from her College of Science Christmas Lecture in December 2023, she plans to upscale her social media presence once her makerspace is up and running.

Her role at the University isn't just about engaging the public—she also hopes to secure grant funding to support research at Notre Dame. The ability to communicate science is a necessary part of completing grant applications, so Biberdorf hopes to serve as a resource and guide for faculty applying for competitive grants.

Ultimately, Biberdorf's appointment marks a major milestone in Notre Dame's commitment to public science engagement. The College of Science is entering an exciting new phase, building on its reputation in research and education while emphasizing the importance of connecting science with the broader community. By making science accessible, engaging, and even a little bit explosive, Kate the Chemist is going to transform the way people perceive and interact with Notre Dame Science, one thrilling experiment at a time.

From Campus to Community: How the Brain Ambassadors are Making an Impact in Michiana

by Ryan Gutierrez '27

Neuroscience is often thought of as a complex and specialized field, confined to lecture halls and research labs. However, a group of dedicated students at the University of Notre Dame is working to change that perception. The Brain Ambassadors program, part of the Neuroscience and Behavior major's community engagement initiative, aims to bring hands-on neuroscience education to the broader community. Through interactive outreach efforts, these students are making a meaningful impact by fostering curiosity and spreading knowledge about the brain beyond the university setting.

The Brain Ambassadors program is a pilot initiative that allows students to serve as neuroscience educators in the community. Neuroscience students can also enroll in an elective course, taught by Dr. Nancy Michael and Dr. Vanessa Chan-Devaere, which provides specialized training in neuroscience content, activity design, and outreach logistics. The course not only deepens students' understanding of neuroscience but also prepares them to communicate complex scientific concepts in engaging and accessible ways.

A key feature of the program is its hands-on approach. Community organizations can request visits from Brain Ambassadors, who then design and lead interactive neuroscience activities tailored to various audiences. These visits take place outside of class time, reinforcing the students' commitment to community engagement and science education. For example, the group hosted a Brains Ambassadors Children's Event at the Saint Joseph County Public Library, educating children ages 6 to 11.

One of the most prominent events led by Brain Ambassadors is the annual Brain Awareness Fair. Held in partnership with local organizations, this free event features hands-on activities that introduce children and community members to fundamental neuroscience concepts. From exploring real human brains to engaging in sensory experiments, attendees get a firsthand look at how the brain functions in every-

ND Brain Ambassadors engaging attendees with an educational activity at the local Brain Awareness Fair.

day life. The 2025 Brain Awareness Fair took place at Howard Park Event Center on Saturday, March 22, from 11:00 a.m. to 2:00 p.m.

Beyond the fair, Brain Ambassadors also visit schools, libraries, and other community centers, tailoring their presentations to audiences ranging from elementary school students to adults. Their activities often include demonstrations on neuroplasticity, memory, and the effects of different stimuli on the brain. These experiences not only make neuroscience more accessible but also inspire younger students to consider careers in STEM fields.

For the students involved, the Brain Ambassadors program provides more than just academic credit—it is an opportunity to develop essential skills in science communication, leadership, and public engagement. Through their outreach work, participants learn how to break down complex topics into digestible, interactive lessons for their younger learners. They also gain firsthand experience in organizing and executing educational events, a skill set that is valuable in every career path, including medicine, research, and science advocacy.

Students who take part in the program often describe it as a transformative experience. By interacting with diverse groups and answering thought-provoking questions from curious minds, they gain a deeper appreciation for the impact of neuroscience education. Many participants find that the program strengthens their passion for both neuroscience and community service, reinforcing their commitment to using science as a tool for positive social change.

The Brain Ambassadors program is a testament to the University's commitment to bridging the gap between academia and the public. By empowering students to share their knowledge, the initiative fosters a greater understanding of neuroscience in the broader Michiana community while providing invaluable experiential learning for participants. As the program continues to grow, it has the potential to inspire even more students and community members, ensuring that the study of the brain remains both accessible and engaging.

The Brain Ambassadors of Notre Dame are proving that neuroscience isn't just for scientists—it's for everyone. By taking their knowledge beyond the classroom and into the community, these students are making a lasting impact, one brain at a time.

Outwit, Outlast, Outplay – In the Classroom

by Alonso Pacheco De Loera '28

What if your next college class felt more like a reality show? Imagine forming alliances, outwitting opponents, and navigating social dynamics—all while earning credit. A new psychology elective, Outwit, Outlast, Outplay: The Dynamics of Survivor, takes the strategies of the legendary reality show and turns them into a hands-on lesson in decision-making, psychology, and game theory. From competing in immunity challenges to surviving tribal councils, students don't just study the game—they play it.

The class was piloted during the London 2024 Summer Abroad Program by Dr. Vanessa Chan-Devaere and Dr. Brian Mulholland. It was so successful it was brought back to the main campus for the first time this year. The class makes the game come to life—exploring the game's biggest moves and wildest betrayals using psychology, neuroscience, and math. Students learn why people make the choices they do—whether it's forming alliances, backstabbing friends, or just trying to stay in the game. Taking the class will drop you headfirst into the actual game of Survivor simulated over the course of the semester. From the first week, students are divided into four different tribes: Gau, Kahne, Kachi, and Noeth. Every week, there's an immunity challenge in class, where students compete against the opposing tribe in various activities, such as a campus-wide scavenger hunt and a brain-balancing duel. The game's most infamous aspect lives on throughout the semester, as tribal councils are held before class, where individuals are "voted off" the tribe and join the production team.

The class isn't all fun and games, however. Throughout the semester, students will learn the mathematics of game theory, which helps predict what players should do to maximize their chances of winning. That being said, people aren't robots, and so students become well-versed in psychology, which they will learn to apply once logic fails and irrational tendencies take over (like trusting someone who just lied to them). That being said, the class sets itself apart from traditional math and psychology courses through its unique approach. It's way more interactive and case-study based. Instead of memorizing formulas or running lab experiments, students break down real game moves, analyze player strategies, and apply what they learn to real-world situations.

Despite the focus on *Survivor*, there is no need to be a superfan to benefit from this class. In fact, the class's creators emphasize that it's for anyone who wants to understand how people negotiate, strategize, and influence others. It's fascinating to learn how group identity is formed and how social psychology influences the way that people interact with one another. Whether you're in business, law, medicine, or just trying to win an argument with your roommate, these skills are important everywhere. The class also counts for the core integration credit, making a valuable addition to any schedule.

Castaways in the Dynamics of Survivor *class pose with special guest, Kelley Wentworth, who competed on three different seasons of* Survivor.

ND Researchers Detect Elevated Levels of PFAS in Smartwatches

by Finley Shinnick '28

Over the past 50 years, synthetic materials have become an inescapable part of daily life. From the plastic particles in urban dust to the microplastics found in our coffee pods, synthetic products infiltrate our bodies continuously. While much attention has been given to plastic pollution, lesser-known but equally persistent chemicals, per- and poly-fluoroalkyl substances (PFAS), pose a growing concern. These synthetic compounds are widely used for their durability and resistance to water, oil, and heat, but their inability to break down makes them a long-lasting presence in both the environment and the human body. PFAS can enter the body through ingestion, inhalation, and skin contact, raising concerns about everyday exposure sources.

Given that approximately one in five Americans wears a wristwatch or fitness tracker, Dr. Graham F. Peaslee and his team at the University of Notre Dame set out to investigate whether wristbands could be a significant source of PFAS exposure. The researchers collected both new and used wristbands made from a variety of materials, including plastic, rubber, leather, and fabric. They analyzed the samples using particle-induced gamma-ray emission (PIGE) spectroscopy, a technique available at the St. Andre accelerator within Notre Dame's Nuclear Science Laboratory. By bombarding the wristbands with high-energy protons, the team was able to measure fluorine levels—a key indicator of PFAS presence. To ensure accuracy, they also tested known paper standards to calibrate their measurements and quantify the PFAS concentrations.

The study revealed that synthetic wristbands, particularly those made of plastic and rubber, contained significantly higher levels of fluorine compared to those made from natural materials like leather or fabric. Additionally, the team applied oxidation and heat treatments to the wristbands, which resulted in the extreme release of PFHxA, a commonly detected PFAS compound. This finding raises concerns about prolonged skin contact during sweat and heat that strongly contribute to human exposure.

Graham F. Peaslee, professor emeritus, joined the Department of Physics and Astronomy in 2016.

These findings highlight the need for increased scrutiny of consumer products as potential sources of PFAS exposure. Given the persistence of these chemicals in the environment and their potential health risks, further research is necessary to determine the long-term effects of wearing synthetic wristbands. In the meantime, consumers may want to consider alternative materials, and manufacturers should explore safer, non-fluorinated options for wearable accessories. Dr. Peaslee's study contributes to the growing body of research underscoring the pervasive nature of PFAS—offering a potential way to reduce unnecessary exposure to these persistent chemicals.

Globe Trotters: 87 Percent of ND Undergrads Abroad

by Ina Satpathy '27

The University of Notre Dame has earned national recognition for its commitment to international education, as highlighted in the 2022-23 Open Doors report from the Institute of International Education (IIE). The report reveals that undergraduate study abroad participation at Notre Dame has reached an all-time high of 87.5 percent, a remarkable increase of over 10 percentage points from the previous year's 77 percent. This surge places Notre Dame third among doctorate-granting universities in the United States for the number of students enrolled in international programs, reinforcing the university's dedication to global education.

Several factors contributed to this impressive growth in study abroad participation. One of the primary drivers is the increased flexibility offered by Notre Dame Global's study abroad team. Over the last three years, the team has reopened the application period each spring, providing additional opportunities for students to apply or resubmit applications. This flexibility has ensured that more students, including those who missed the original deadline or faced unforeseen circumstances, were able to participate in study abroad programs.

In addition, Notre Dame's colleges and schools have worked closely with Notre Dame Global to better integrate study abroad opportunities into the academic curriculum. This collaboration has made it easier for students to incorporate global learning into their educational journey, ensuring that study abroad is seen as an essential component of their academic experience rather than an extracurricular activity. As a result, more students are making global education a priority, which has significantly boosted participation rates.

Senior Director of Global Education at Notre Dame Global, Hong Zhu, expressed excitement over the university's rankings. "We are thrilled with this year's rankings," she said, highlighting that the participation rate reflects how much students value global education. "Students recognize that global education is an essential part of their Notre Dame education and make room for it in their academic journey." Zhu also emphasized that rankings represent only part of the success. "Much credit goes to the entire study abroad team and the advising deans and faculty who support students in this endeavor," she added.

Notre Dame Global offers a wide array of study abroad programs, including 58 semester and year-long programs and 34 summer programs across 35 countries. These programs provide students with opportunities to immerse themselves in local cultures, participate in internships, and collaborate on research projects with leading academics. These experiences help students develop critical global competencies, enhancing their ability to navigate a complex and interconnected world.

In addition to academic benefits, Notre Dame's study abroad programs are designed to foster engagement with local communities. Students are encouraged to contribute to global research and projects that have the potential to make a positive impact on communities across the globe. This combination of academic rigor and community involvement allows students to gain a deeper understanding of the world while contributing to meaningful change.

As part of its broader global strategy, Notre Dame is focused on enhancing the intentionality of its study abroad programs. Vice President and Associate Provost for Internationalization, Michael Pippenger, noted that the University seeks to create intellectually rich and culturally immersive experi-

ences. "The University's global strategy calls for us to enhance the intentionality of study abroad programs and to develop experiences that allow students to engage deeply with host cultures through coursework, internships, research, and service," Pippenger explained.

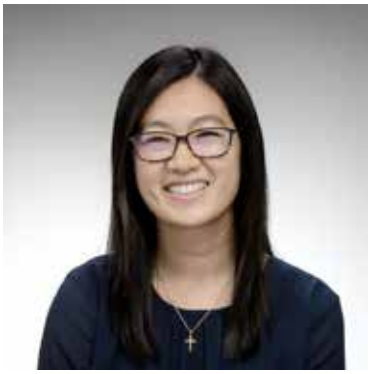
That study abroad is as an integral part of a Notre Dame education is evident in the university's efforts to make these opportunities accessible and impactful for its students. By offering diverse programs that integrate cultural understanding, research, and service, Notre Dame ensures that its students are prepared to be leaders in an increasingly interconnected world.

The Open Doors report, which tracks the number of U.S. students who received academic credit for study abroad, has highlighted the growing significance of international learning. Since its founding in 1919, Open Doors has partnered with the U.S. Department of State's Bureau of Educational and Cultural Affairs to produce its annual survey, underscoring the importance of global education in shaping future leaders.

As study abroad participation at Notre Dame continues to rise, the University remains committed to expanding its global education offerings. With an emphasis on deepening the cultural and academic experiences of its students, Notre Dame is positioning itself as a leader in international education, preparing graduates to address global challenges.

Through its robust global network and commitment to integrating international experiences into its academic framework, Notre Dame is not only enriching the lives of its students but also contributing to a more connected and understanding world. In an increasingly globalized society, the value of international education has never been more crucial, and Notre Dame is leading the charge in preparing students to thrive in a global community.

ACMS Faculty Spotlights



Clare Booth Luce Assistant Professor of Applied Computational Mathematics and Statistics since Fall 2024

Dr. Tiffany Tang is a Clare Boothe Luce Assistant Professor in the Department of Applied and Computational Mathematics and Statistics. She earned her BA and BS in statistics and mathematics from Rice University in 2018 and her PhD in statistics from the University of California, Berkeley in 2023. She then worked as a postdoctoral researcher at the University of Michigan's Department of Statistics with Dr. Ji Zhu and Dr. Liza Levina. Dr. Tang's research is problem-driven and lies at the intersection of statistics, data science, and medicine. Her work focuses on developing interpretable statistical machine learning methods to extract actionable and reliable insights from real-world data. She is particularly interested in ensuring the transparent and responsible use of AI in healthcare through close collaboration with domain scientists. Additionally, she creates open-source tools and software to facilitate the broader adoption of reliable data science in practice.

Assistant Professor since Fall 2024

Dr. Soham Jana is an assistant professor in the Department of Applied and Computational Mathematics and Statistics at the University of Notre Dame. He earned his BStat and MStat with a specialization in theoretical statistics from the Indian Statistical Institute (ISI), Kolkata. For his master's dissertation, he worked on minimum distance estimators that avoid kernel smoothing in the estimation process under the guidance of Dr. Ayanendranath Basu. He then completed his PhD in the Department of Statistics and Data Science at Yale University. Following his doctoral studies, he was a postdoctoral research associate at Princeton University's Operations Research and Financial Engineering (ORFE) department. Dr. Jana's research focuses on the theoretical and methodological aspects of statistics and machine learning. His interests include robustness, empirical Bayes methods, mixture modeling, and causal inference. Through his work, he aims to develop rigorous statistical frameworks that enhance the reliability and interpretability of data-driven decision-making.

Biological Sciences Faculty Spotlights

Associate Professor since Fall 2024

Dr. Pilar Pérez Romero is an associate professor in the Department of Biological Sciences at the University of Notre Dame. She earned her PhD in biological sciences from the University of Seville, Spain, in 2000. Following her doctorate, Dr. Pérez Romero was a postdoctoral scientist at the University of Michigan from 2001 to 2005. She later held positions as a junior faculty member at the Biomedical Institute of Seville (2006–2017) and as an associate professor in virology at the National Centre for Microbiology in Madrid, Spain (2017–2023). Dr. Pérez Romero's research focuses on elucidating virus-host interactions during infection, specifically examining human cytomegalovirus (CMV) and its impact on immune responses. Her lab works on characterizing the interactions between CMV and host cells at the gene expression level, identifying viral gene products that regulate immune responses, and exploring CMV's immune evasion mechanisms. Dr. Romero's research contributes to global health issues by providing insights into pathogen-host interactions, immune responses, and virology.

Assistant Teaching Professor since Fall 2024

Benjamin Rudenga is an assistant teaching professor in the Department of Biological Sciences at the University of Notre Dame. He earned his BS in general biology and industrial management from Purdue University in 2005, followed by an MS in biomedical sciences with a focus on immunology from the University of Connecticut Health Center in 2012. Professor Rudenga is passionate about guiding students through their introductory biology courses, emphasizing the importance of building a welcoming and open classroom atmosphere. In both lecture and laboratory settings, he fosters a collaborative community that sparks curiosity and enthusiasm for biology. He is committed to helping students develop crucial laboratory skills, foundational biological knowledge, and critical thinking abilities. Professor Rudenga also places a strong emphasis on communication, encouraging students to share their research through discussions and written work. His teaching experience spans a range of subjects, from ecology to anatomy and physiology, which he brings to his current role at Notre Dame.

Assistant Professor of the Practice since Spring 2025

Dr. Bharat Mishra joined the University of Notre Dame in 2025 as the principal bioinformatician for the Genome and Bioinformatics Core Facility and assistant professor of the practice in bioinformatics. He provides bioinformatics consultations, analysis support, collaborates on research projects, and trains individuals in biological data science. Dr. Mishra specializes in high-throughput sequencing analysis, including RNA-Seq, single-cell transcriptomics (scRNA-seq), and spatial transcriptomics (ST), among others. His work aims to elucidate cellular functions at novel levels of resolution; he adheres to FAIR data analysis practices, ensuring data is findable, accessible, interoperable, and reusable. He also emphasizes version control, containerization, open-source computational tools, and the use of HPC computation clusters in his work. Dr. Mishra earned his PhD in biology from the University of Alabama at Birmingham in 2022. Before joining Notre Dame, he worked as a bioinformatician III at the UAB-Biological Data Science (U-BDS) Core.

Assistant Research Professor since Spring 2025

Dr. Jianping He is an assistant research professor in the Department of Biological Sciences at the University of Notre Dame. He earned his BS and PhD from Xiamen University, where he researched nuclear receptors and selective autophagy in Dr. Qiao Wu's laboratory. Dr. He then moved to Cold Spring Harbor Laboratory, where he worked with Dr. Linda Van Aelst on organ-specific metastasis as a postdoctoral fellow. In 2019, he joined the Schafer Lab at Notre Dame as a postdoctoral fellow and was promoted to senior scientist in 2023. He became an assistant research professor in 2025. Dr. He's research in the Schafer Lab focuses on understanding the biological mechanisms that allow cancer cells to survive during tumor progression, particularly the changes in cell death programs and metabolism resulting from the detachment of cells from the extracellular matrix (ECM).

Chemistry and Biochemistry Faculty Spotlights

Huisking Foundation, Inc. Assistant Professor of Chemistry and Biochemistry since Spring 2025

Dr. Mariko Morimoto is an assistant professor in the Department of Chemistry and Biochemistry at the University of Notre Dame. She earned her BSc in chemistry from Emory University in 2016 and her PhD in chemistry from the University of California Berkeley in 2021. Following her doctoral studies, Dr. Morimoto was a postdoctoral research associate at Stanford University from 2021 to 2024, and a visiting scientist at Merck & Co. in 2020. Dr. Morimoto's research focuses on chemical immunology, particularly on developing chemical approaches to target immune-regulating mechanisms. One of her key areas of focus is glycans, the sugars that coat the surface of cells and regulate immune responses through interactions with lectins (glycan-binding proteins). Her work aims to uncover new strategies for targeting glycan-lectin interactions, a promising avenue in immunotherapy. Another research focus is the design and synthesis of small molecules and biologics that modulate protein-protein interactions (PPIs) in immune cells to restore their healthy function. Dr. Morimoto's interdisciplinary lab integrates synthetic organic chemistry, chemical biology, biomolecular engineering, and immunology, offering trainees the opportunity to develop expertise across these fields.

Grace-Rupley Professor of Chemical Biology since Spring 2025

Dr. Herman Sintim is the Grace-Rupley Professor of Chemical Biology at the University of Notre Dame and serves as the associate director of the Harper Cancer Research Institute. He earned his PhD in organic chemistry from the University of Oxford in 2002 and completed postdoctoral fellowships at Stanford University and Oxford University. Dr. Sintim held faculty positions at the University of Maryland at College Park from 2006 to 2015 before joining Purdue University as a distinguished professor. His research focuses on cyclic dinucleotide signaling, particularly in relation to bacterial processes and immune responses in mammalian cells, and aims to develop novel therapeutics targeting cyclic dinucleotide pathways. Dr. Sintim's group also explores the synthesis of kinase inhibitors to combat cancer drug resistance, focusing on secondary mutated kinases and kinases involved in the tumor microenvironment. His interdisciplinary work integrates computational and experimental techniques to identify and optimize new drug candidates.

Associate Teaching Professor since Fall 2024

Dr. Dana Lashley is currently an associate teaching professor at the University of Notre Dame. Prior to this, she served at William & Mary from 2014 to 2024, where she served as an associate teaching professor. She earned her PhD in synthetic organic chemistry and medicinal chemistry from Auburn University in 2014 and her MS and Vordiplom in chemistry and physics from Goethe University Frankfurt in Germany. Her past research has focused on medicinal chemistry, specifically the organic synthesis of compounds with potential medicinal properties for early preclinical drug discovery. Her work includes synthesizing quinone natural products and inhibiting mitochondrial complex I. Dr. Lashley has been recognized for her contributions, receiving awards such as the College of Arts & Sciences Award for Faculty Governance (2022), William & Mary Diversity Champion (2021), and William & Mary Woman of Influence (2019-2020).

Teaching Professor and Professor of Public Engagement since Fall 2024

Dr. Kate Biberdorf, known widely as Kate the Chemist, is Professor for Public Understanding of Science and a teaching professor at the University of Notre Dame. Previously, she was an associate professor of instruction at the University of Texas at Austin, where she also served as director of demonstrations and outreach and ChemBridge coordinator. She earned her PhD in inorganic chemistry from the University of Texas at Austin in 2014 and her BS in chemistry and German from the University of Michigan in 2008. A dynamic educator and science entertainer, Dr. Biberdorf uses a hands-on, theatrical approach to teaching, aiming to dismantle the stereotypical image of a scientist. She is the author of *The Big Book of Experiments* and *The Awesome Book of Edible Experiments for Kids*, among other works, and has been featured in *The Washington Post*, *The Wall Street Journal*, *The New York Times*, and on popular shows like *The Today Show* and *The Kelly Clarkson Show*.

Assistant Research Professor since Spring 2025

Dr. Pratik Yadav is an assistant research professor in the Department of Chemistry and Biochemistry at the University of Notre Dame. He completed a postdoctoral research fellowship at Purdue University, where he collaborated with the ND Institute of Drug Discovery on exploring novel compounds and mechanisms for drug development. With over eight years of experience in organic chemistry research and teaching, Dr. Yadav has a strong background in mass spectrometry and nuclear magnetic resonance (NMR), which he uses to analyze and characterize complex organic molecules and reactions. He also served as an assistant professor at Kirori Mal College, University of Delhi, where he taught and mentored undergraduate students in organic chemistry. Dr. Yadav is passionate about advancing innovation in organic chemistry and drug discovery and values collaboration and creativity in his work. He is a DAAD Fellow, a prestigious recognition for young researchers in chemistry.

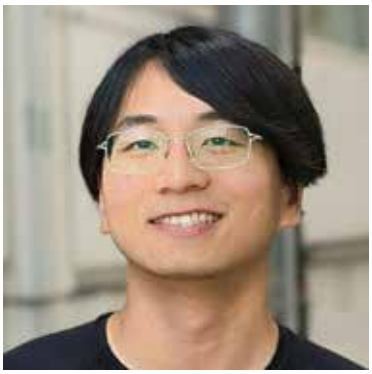
Physics and Astronomy Faculty Spotlights

Assistant Professor since Fall 2025

Dr. Kateryna Foyevtsova is an assistant professor in the Department of Physics and Astronomy at the University of Notre Dame. She completed her BS at Lviv National Polytechnic University (2004), MS at Minnesota State University (2006), and PhD at Goethe University Frankfurt in Germany (2011). Before her current role, Dr. Foyevtsova was a senior scientist and research associate at the Stewart Blusson Quantum Matter Institute at the University of British Columbia. Her research focuses on correlated oxides, frustrated spin systems, and the study of electron-boson interactions, especially in the context of high-transition-temperature (high-Tc) superconductivity. Dr. Foyevtsova's work aims to uncover the underlying physics of these complex materials, bridging theory and experiment to enhance our understanding of quantum materials with applications in energy technologies and quantum information systems.

Teaching Professor since Fall 2024

Dr. David Robertson is a teaching professor in the Department of Physics and Astronomy at the University of Notre Dame. He earned his BS with honors from the University of California, Los Angeles and his PhD from the University of California, Santa Barbara. Before joining Notre Dame, Dr. Robertson was a faculty member at Otterbein University from 2002 to 2024, where he taught a broad range of courses across the physics curriculum, including in the honors and integrative studies programs. During his time at Otterbein, he served as chair of the Department of Physics and director of Undergraduate Research and Creative Work. In 2017, he was named Otterbein University's Teacher of the Year. Dr. Robertson's research interests include elementary particle physics, high-performance computing, and computational tools for precision calculations in quantum field theories. He has also contributed to Hamiltonian approaches to strongly interacting field theories and particle physics phenomenology, with a particular focus on the light cone formalism.



Assistant Research Professor since Spring 2025

Dr. Yutian Wen is an assistant research professor in the Department of Physics and Astronomy. He specializes in quantum fluids, spintronics, and circuit QED. Dr. Wen completed his DPhil in Materials Science at the University of Oxford, where he focused on the development and understanding of advanced quantum materials. Following his doctoral studies, he held postdoctoral positions at CEA Paris-Saclay and ENS de Lyon, where he contributed to pioneering work in quantum technologies. His research aims to explore quantum fluid behavior, spintronic applications, and the integration of quantum devices in future technologies. Dr. Wen holds a BEng in electrical engineering from Shanghai Jiao Tong University, which laid the foundation for his interest in quantum systems and material science.

Research Professor since Fall 2024

Dr. Alexei Koshelev is a research professor in the Department of Physics and Astronomy at the University of Notre Dame. He earned his PhD from the Landau Institute of Theoretical Physics in 1986. Dr. Koshelev has an extensive career in the field of theoretical physics, particularly focusing on superconductivity and vortex matter in layered superconductors. Prior to joining Notre Dame in 2024, he spent over 30 years at Argonne National Laboratory as a physicist in the Materials Science Division. Dr. Koshelev's research is aimed at advancing our understanding of physical phenomena in materials, using both analytical models and numerical simulations to describe experimental data and predict new phenomena. His specific research interests include vortex pinning, intrinsic Josephson effects, terahertz electromagnetic wave generation, multiple-band superconductivity, and transport in antiferromagnetic metals. Koshelev has received numerous honors for his contributions to physics, including the University of Chicago Distinguished Performance Award in 1998, election as a Fellow of the American Physical Society in 2003, and the 2015 Abrikosov prize in Vortex Matter.

Mathematics Faculty Spotlight

Assistant Professor since Fall 2024

Dr. Shuddhodan Kadattur Vasudevan is currently an assistant professor at the University of Notre Dame, specializing in arithmetic and algebraic geometry. He earned his PhD in mathematics from the Tata Institute of Fundamental Research in Mumbai in 2018, supervised by Prof. Vasudevan Srinivas. His research focuses on the interaction between arithmetic, algebraic, and topological aspects of geometry, particularly questions that involve the interplay of these fields. Before joining Notre Dame, Dr. Vasudevan was a CARMIN Fellow at the Institut des Hautes Études Scientifiques (IHES) in Bures-sur-Yvette, France. He also served as a Golomb Visiting Assistant Professor at Purdue University from August 2019 to August 2022, following postdoctoral work at the Einstein Institute of Mathematics in Jerusalem and the Freie Universität Berlin.

Pre-professional Studies Faculty Spotlight

Assistant Advising Professor since Fall 2024

Dr. Henry Vu is an assistant advising professor at the University of Notre Dame, where he guides students in the Center for Health Sciences Advising, helping them prepare to apply to health profession schools. With extensive research experience, Dr. Vu is dedicated to mentoring students to help them achieve their goals. He holds a bachelor of science and master of arts in biology from Villanova University, as well as a PhD in biological sciences from the University of Notre Dame. He completed his postdoctoral research with Dr. Shaun Lee. Dr. Vu's research interests include studying bacterial manipulation of the human coagulation system and exploring how antifreeze proteins aid in insect survival in extreme temperatures. Outside of academia, Dr. Vu is the head coach for the girls' soccer team at Marian High School in Mishawaka, Indiana; his team has been State Runner-Up twice. His dedication to excellence and coaching has led him to earn the titles of District Coach of the Year and NIC Conference Coach of the Year twice.

Seasonality of Waterborne Pathogens Detected Using Next Generation Sequencing (NGS) Approach in Belize, Central America

by Grace Billhartz '25

ABSTRACT

Waterborne diseases pose significant public health concerns and contribute to increasing rates of morbidity and mortality. The country of Belize, on the Yucatan Peninsula, struggles with endemic infections such as cholera, typhoid fever, and diarrheal diseases as a result of unsanitary water conditions. Much is unknown about how changes in climate, specifically changes in precipitation rate, can affect what types of pathogens are present in water. This study investigated whether pathogens found in water samples differed between Belize's wet and dry seasons, and how these potential differences could affect human populations. Water samples were collected by the Belize Vector and Ecology Center team during the wet and dry seasons between November 2021 and May 2024. Oxford Nanopore Sequencing platforms were used to sequence samples. Pathogens detected from samples collected in the early and late wet seasons were compared with pathogens detected from samples collected in the early and late dry seasons. A greater abundance of pathogens were present in the wet season compared to the dry season samples. Although the presence of pathogen genetic material does not directly translate to disease probability, results from this study are expected to provide new knowledge on the use of seasonal water surveillance in assessing health risks for human populations in Belize.

INTRODUCTION

Waterborne microbial diseases are one of the leading causes of death worldwide and are often transmitted to humans as a result of poor sanitation and water contamination [1,2]. Although many of these diseases have been nearly eradicated in industrialized countries, up to 13 million people in developing nations die from consuming unsafe water every year [2]. Contaminated water poses many health risks to communities and facilitates the transmission of diseases like cholera, diarrhea, hepatitis A, typhoid, and poliomyelitis [1]. These diseases, as well as other waterborne infections, are caused by a variety of pathogens including viruses and bacteria. For this reason, detection and analysis of these pathogens is vital for characterizing risk of community exposure, disease prevention strategies, and administering suitable educational material.

One country that lacks universal access to adequate water treatment facilities is Belize, causing a portion of its population to be at an increased risk of contracting waterborne infections. It is estimated that only 11% of Belize's population has access to sewage services, including wastewater collection and treatment [3]. A large portion of the surface water in urban areas is contaminated due to inadequate disposal of household, agricultural, and industrial waste. In rural areas, access to sanitation is limited by the use of pit latrines and septic tanks [3,4].

Belize experiences distinct wet and dry seasons, which can be further divided into early and late periods. The early wet season typically falls from June to July, with approximately 75-200 mm of rainfall per month in the northern regions, and 200-650 mm of rainfall per month in the south. The early wet season often experiences heavier rainfall compared to the late wet season due to the increased prevalence of tropical storms and hurricanes [6]. However, rainfall can vary significantly depending on the given year or specific location within the country. The early dry season is from January to February, when the average rainfall is minimal (typically less than 50 mm of rain during these months). The late dry season is from March to May and sees an estimated 25-150 mm of rainfall as the country transitions to the start of the wet season. Seasonality can impact pathogen distribution and waterborne disease spread. Heavy rainfall can increase pathogen mobility by increasing water source abundance. Drought can restrict pathogen movement by elevating pathogen concentrations in existing water reservoirs [7].

Because the epidemiological impacts of waterborne diseases in Belize changes across seasons, it is crucial to accurately assess which pathogens are present during the wet and dry seasons. While the existence of waterborne diseases in Belize is widely known, it is less understood which species of pathogens are present in each season. This information could assist healthcare workers in identifying which pathogens are most likely to be present at specific times of year. It is expected that there will be a greater abundance of waterborne pathogens in the wet season compared to the dry season due to the effects of rainfall on pathogen mobility.

METHODOLOGY

1. Water Sample Collection

Water sampling was performed from November 2021 to May 2024 in both wet and dry seasons. Samples were collected from 17 routine sampling locations within all six political districts using REDI-NET field collection Standard Operating Procedures [8]. This selection included Corozal (3), Orange Walk (8), Stann Creek (1), Belize (2), Cayo (2), and Toledo (1) districts (Figure 1).

Figure 1. Map of Water Sampling Sites. The left figure shows the six political districts of Belize (URL: en.wikipedia.org/wiki/Belize. Accessed Jan. 2025). The right figure illustrates the routine sampling sites from which water samples were collected (URL: redinet.crc.nd.edu/bvec/water. Accessed Jan. 2025).

2. Water Processing

All samples were processed according to the REDI-NET W-2 Water Processing SOP[9] (Figure 2). Water filtration was performed at the Belize Vector and Ecology Center (BVEC) and TNA extraction was completed at either BVEC or the University of Notre Dame.

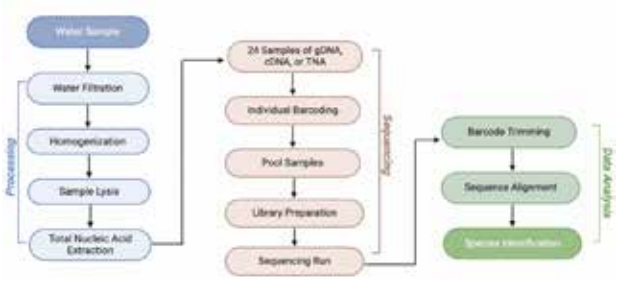


Figure 2. Overview of Water Processing and Sequencing Procedural Steps Utilized for Pathogen Identification. Outline of steps followed to process, sequence, and identify potential waterborne pathogens present in water samples. URL: https://redinet.crc.nd.edu/bvec/water. Accessed January 2025).

Water samples were filtered using a Versapor acrylic copolymer 47 mm diameter, 5 µm pore membrane disc (Cytiva, USA). A PEG-8000 solution was added to the pre-filtered water samples and stored at 4°C overnight for particle aggregation. Next, the PEG-8000 treated water samples were filtered through a 0.45 µm GN-6 membrane (Cytiva, USA) for microorganism collection. Membranes were treated with DNA/RNA Shield Reagent (Zymo Research, USA) and stored at -20°C.

Membrane samples were halved and cut into 3 mm pieces that were placed in 1.5 mL microtubes containing 200 µL zirconium oxide beads (Thermo Fisher Scientific, USA) and four 3.5 mm Stainless Steel UFO beating beads (Next Advance, USA). Samples were extracted using a IndiMag Pathogen Kit (Indical Bioscience GmbH, Germany) following manufacturer's instructions. After extraction, DNA and RNA concentrations were recorded using a Qubit 4.0 fluorometer (Thermo Fisher Scientific, USA).

3. Sample Sequencing

Next-generation sequencing was performed with MinION or GridION (Oxford Nanopore Technologies, UK) sequencers using REDI-NET Standard Operating Procedures [10]. Multiple approaches were used over the course of the study including gDNA, cDNA, or TNA (Total Nucleic Acid) sequencing. Sequencing outputs were analyzed as described in Steffen et al [11]. using the custom designed REDI-NET NGS platform.

To determine the presence of waterborne pathogens among these samples, the microorganisms detected in water samples were compared to a list of waterborne pathogens constructed following classification guidelines from the Center for Disease Control [12], Health Canada [13], and World Health Organization [14].

RESULTS

A total of 663 samples were collected between November 2021 and May 2024. Among them, 283 samples were collected during the early dry season, 196 samples from the late dry season, 96 samples from the early wet season, and 88 samples from the late wet season (Table 1). Some of the collected samples remained unprocessed due to challenges with transport, storage, or expiration.

A total of 430 water samples were subjected to TNA extraction. Extracted samples were then subject to gDNA, cDNA or TNA sequencing (Table 1). Among all the water samples sequenced, 426 different microbial species were detected, and 30 sequenced samples were characterized using NGS technologies as potential waterborne pathogens (Table 1).

Table 1.

	Early Dry (Jan-Feb)	Late Dry (March-May)	Early Wet (June-July)	Late Wet (Aug-Dec)
Samples Collected	283	196	96	88
Samples w/ TNA Extracted	132	172	53	73
Samples Sequenced	108	107	19	56
Sequenced samples positive for Waterborne Pathogens (WBP)	12	7	2	9

Figure 3 shows the number of processed samples positive for waterborne pathogens out of the total number of samples processed during each season. Late wet season showed the highest percentage of samples (>16%) positive for waterborne pathogens.

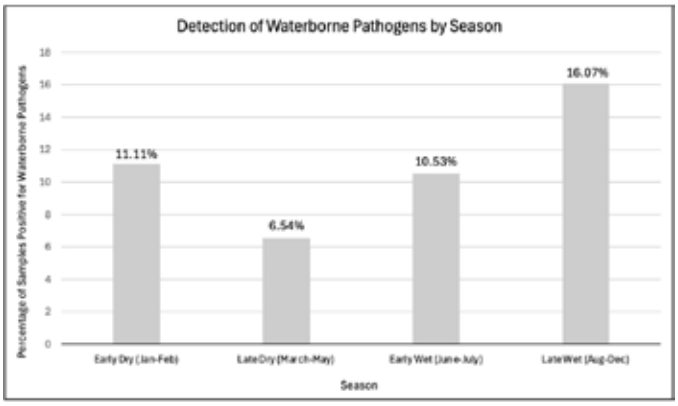


Figure 3. Detection of Waterborne Pathogens by Season. Percentage of samples positive for waterborne pathogens out of the total number of sequenced samples.

DISCUSSION

The aim of this study was to investigate whether the abundance of waterborne pathogens differed across Belize's wet and dry seasons. Results suggest that more waterborne pathogens are present in the wet season compared to the dry season, possibly due to the effects of rainfall on pathogen mobility. These findings support the idea that the risk of contracting certain waterborne infections exhibits seasonal variation.

Despite these findings, it is important to recognize limitations within this study that could have impacted its results. Specifically, the overlap between Belize's wet and dry seasons complicates identifying each pathogen's season of origin, as some may persist from previous seasons. There were also sampling site restrictions based on location and/or time of year. Field teams experienced collection interruptions in the wet seasons due to periods of heavy rainfall, whereas collections occurred more regularly during the dry seasons. This complication could bias results when comparing the percentages of waterborne pathogens detected during each season. Natural disasters and weather abnormalities occurring during this time period, such as Hurricane Lisa in November 2022, caused extensive damage and flooding. These events could have impacted the volume and types of pathogens present in specific seasons because of environmental changes, increases in vector breeding sites, and/or damage to water reservoirs which could have worsened sanitation conditions [15]. Finally, given the challenges and potential biases associated with shotgun metagenomic sequencing, caution should be taken against overinterpreting results. It is recommended that secondary confirmation is conducted to validate the number (and species) of pathogens detected in this study [16].

Future studies could expand collection periods and locations, which would offer a more robust data set to track pathogen mobility and distribution. Subsequent research could also quantify differences in pathogens identified, as well as investigate specific pathogens of interest in order to reach a more comprehensive understanding of how seasonality impacts health risks associated with waterborne diseases in Belize.

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What's Up, Doc? A Qualitative Analysis of Physicians' Opinions on the Effectiveness Regarding the Length and Courses in Medical Schools' Curriculum

by Enanu Smart '27

ABSTRACT

The United States is facing an impending physician shortage, projected to reach between 37,800 and 124,000 physicians by 2034 [1]. One proposed solution is to condense the length of medical education by eliminating potentially unnecessary coursework. While previous research suggests that medical school's rigor, cost, and duration deter students from pursuing a career in medicine [2], there remains debate regarding whether curriculum reduction would compromise educational quality. This study explores physicians' perspectives on the effectiveness of the current medical school curriculum, focusing on its length and course content.

Semi-structured interviews were conducted with 16 licensed physicians from diverse specialties to examine their views on the necessity of current medical school coursework and the potential feasibility of curriculum reduction. Thematic analysis revealed three major findings: 1) Medical school provides a foundational knowledge base that, while not always immediately applicable, is essential for residency training and lifelong learning; 2) The traditional two-year preclinical and two-year clinical structure effectively prepares students for clinical rotations and should be maintained; and 3) Shortening medical school risks compromising educational quality, potentially affecting physicians' ability to provide adequate care.

Although some physicians acknowledged redundancy in certain introductory science courses, they emphasized that this repetition accommodates students from varied undergraduate backgrounds. The findings suggest that condensing medical education is not a viable solution to the physician shortage. Instead, future research should explore alternative strategies, such as optimizing pre-medical education, restructuring residency training, and implementing financial incentives to make medical education more accessible without sacrificing quality.

INTRODUCTION

Physicians play a vital role in maintaining a community's health. Despite their necessity, trends indicate an impending shortage of physicians in America, which could jeopardize the quality and availability of medical care. Several factors contributing to this predicted shortage include the length, course load, and cost of medical school, all of which may discourage students from pursuing a medical career.

After completing an undergraduate degree, medical school requires four more years of education, leading to substantial tuition expenses. Beyond the financial burden, the extensive time commitment further deters potential candidates. While three-year medical school programs have been proposed as a solution, research suggests that their accelerated pace creates even greater stress compared to traditional programs. As a result, no effective solution currently exists to mitigate the rigor of medical education.

However, additional research suggests that not all content in medical school curricula is directly applicable to physicians' daily practice. This raises the possibility of streamlining medical education by eliminating non-essential material, potentially reducing the length of training without compromising the quality of care.

To explore this possibility, I will conduct semi-structured interviews with 16 physicians to gather their perspectives on the relevance of medical school curricula to their current practice. Their insights will provide a deeper understanding of whether certain aspects of the curriculum could be revised or removed due to their lack of applicability. By evaluating the feasibility of condensing medical education, future research can build on these findings to help increase the number of students entering medical school. Ultimately, increasing medical school enrollment could help mitigate the projected physician shortage. Given the growing demand for physicians and the barriers posed by the length and cost of medical education, this study seeks to answer the question: What are physicians' opinions on the effectiveness of the length and courses in medical schools' curricula?

LITERATURE REVIEW

Over the past two decades, the United States has faced a growing physician shortage, with projections estimating a shortfall of 37,800 to 124,000 physicians by 2034 [1]. Several factors contribute to this issue, including an aging physician workforce, with many nearing retirement, further exacerbating limitations in medical availability [3]. As a result, addressing this shortage requires significant investment in the education and training of future physicians [4].

One of the primary barriers to entering the medical profession is the length and cost of medical education. Traditional medical school programs span four years, with average tuition costs exceeding $230,000 [2]. In response to these financial and time constraints, accelerated three-year programs have been proposed as a potential solution. However, research suggests that while these programs may reduce costs, they also impose significant stress on students, raising concerns about their feasibility and long-term effectiveness [5].

Alternatively, Al-Shamsi [6] argues that shortening the duration of medical education could be a viable strategy to mitigate the physician shortage. His research indicates a moderate correlation between medical school performance and post-graduate success, suggesting that much of the content taught in traditional programs is not directly applicable to daily medical practice. As a solution, he proposes a restructured curriculum that emphasizes essential knowledge while integrating pre-clinical and clinical training to improve retention and practice-based learning.

Further supporting the need for curriculum reform, Kishita et al. [7] emphasize the importance of continuously evaluating medical school curricula to ensure they foster both student success and high-quality patient care. Their findings suggest that a well-structured curriculum, regardless of duration, should balance academic rigor with practical application to ensure graduates are adequately prepared for clinical practice.

As a result, this review aims to assess the effectiveness of medical school curricula in addressing barriers to entry while ensuring physician preparedness. Specifically, this review will explore whether condensing medical education can reduce financial and time-related obstacles for prospective students while contributing to long-term solutions for the physician shortage.

METHODOLOGY

Following the methodology of Kishita et al. and Todres et al., I conducted research through semi-structured interviews [7,8]. Given that Todres et al.'s study examined "medical students' perceptions of the factors influencing their academic performance," it provided a framework for shaping the questions used in my interviews. Semi-structured interviews allow for the collection of qualitative data, which tends to be open-ended, enabling an exploration of participants' thoughts, feelings, and beliefs about a particular topic [9]. This approach was instrumental in developing an answer to my research question and assessing the feasibility of condensing the medical school curriculum concerning its applicability to a physician's daily practice.

My research model consisted of interviewing a total of 16 physicians. Similarly to Kishita et al.'s research, I interviewed the graduates of the program in order to acquire relative knowledge of the curriculum present in medical school. Creswell suggested acquiring between five and 25 participants due to the nature of the method being semi-structured interviews, meaning more in-depth questions [10]. The main inclusion criteria for physician's participation required: 1) at least five years into certified medical practice and 2) attending an American medical school. The five years of certified medical practice helped ensure time to develop real-world experiences and application of their education from medical school [11]. In order to obtain the desired interviewees, an informational interest form was sent out to 30 physicians' emails, which were obtained from a local physician's contacts. Thirty emails created a buffer in acquiring the desired number of voluntary participants. Upon receiving responses, interviews were scheduled either virtually or face-to-face, along with signing consent and Institutional Review Board (IRB) forms. Within the consent form, participants indicated consent to record their interview for fidelity purposes. The interviews were conducted over three months, followed by data analysis.

The first section of questioning regarded introductory and demographic questions that mirrored those in Todres et al.'s research (see Chart 1.0). The answers to these questions were then charted but never explicitly used in the paper. Instead, it served to ensure the variety of specialties and medical schools attended and assist in the organization of the interviews. After the basic background questions, I began questioning specifically about medical school.

The second section of questions was developed from the combination of the three themes in Todres et al.'s research: "engagement with learning, reflecting on learning methods and experiences, and the application of learning to their future practice" and Kishita et al.'s five different categories: "1. Philosophy, concept, and goal of the program 2. Degrees, curriculum, and staff 3. Students' qualifications and career paths 4. Relationship between education/research activities and real-world practices 5. Enhancing interdisciplinary education." Focusing on the relationship between education, preparedness, and application of knowledge aided in the development of the questions illustrated in Chart 1.0. These questions included ratings which brought numeric terms to easily identify the positive or negative feelings toward a subject. This quantitative measure was combined with a qualitative open-ended explanation of their rating to help answer the research question.

Chart 1.0 – Questions set one

Demographics (name, age, specialty/occupation, med school attended, year of graduation)
For the questions below, on a 1 to 10 scale, how would you rate your engagement with learning in medical school and why?
1 = lowest; 10 = highest
Rate your overall experience of attending medical school and why?
Rate your preparedness for residency and ultimately medical practice as a direct result of medical school and why?
Rate your overall experience in providing medical care as a clinician and why?
Specifically, rate the application of medical school-acquired learning to current (or recent) medical practice and why?

The next set of questions focused on the courses taught in medical school. This section (see Chart 2.0) included questions about condensing medical education to assess potential redundancies in medical curricula. These questions aimed to gauge professionals' perspectives on the adequacy of medical education's current duration and quality.

Chart 2.0 – Questions set two

From a clinician's viewpoint, what are the most necessary and least necessary components of medical school?
If you were tasked with redesigning medical education, what would be your highest priority changes in the curriculum (and why)?
In retrospect, are there specific classes or portions of classes that proved redundant or unnecessary?
Do you believe that condensing medical school is feasible without significant loss of quality?
What barriers would you anticipate in shortening medical school?
In the traditional curriculum, what year of medical school resonates with you as most essential and why?

Each recording was transcribed to code for similarities between responses. The results, derived through frequency analysis, helped identify specific patterns of thought or recurring concepts within the interviews, which were categorized as themes. These themes ultimately formed a coherent set of ideas through patterns in the answers, to help construct the most concise response to the research question.

RESULTS

Ultimately, the majority opinion for each question determined the answer to my research question regarding physicians' perspectives on the effectiveness of the length and courses within medical school curricula. Therefore, when referring to the graphs throughout the text, I highlight the majority opinion from the interviews, as it holds the most influence in shaping the answer to my research question.

The two questions presented in Table 1.0 were asked to begin the semi-structured interviews. These questions establish a baseline understanding of physicians' ability to excel in the demanding medical school environment.

Table 1.0 – Overall Learning Engagement and Experience in Medical School

Question	Commonality	Keywords	Example response	Frequency	Percentage
How would you rate your engagements with learning in medical school and why?	Positive	Enjoyed	I really **enjoyed** medical school. I enjoyed learning and the lectures. My classmates had just great senses of humor	10	62.50%
		Excited			
		Excellent			
		Collegiality			
	Stressful	Intense	Engagement was, out of sheer **terror** and necessity, but not out of any interest.	6	37.50%
		Busy			
		Terror			
Rate your overall experience of attending medical school and why?	Positive	Comrades	**Wonderful** experience. Some of the best years of my entire life.	15	93.75%
		Wonderful			
		Excellent			
	Stressful	Hard	I mean it was **hard**	1	6.25%

Table 1.1 – Rating of Overall Learning Engagement and Experience in Medical School

Question	Rating	Frequency	Percentage
How would you rate your engagements with learning in medical school and why?	10	6	37.50%
	9	5	31.25%
	8	2	12.50%
	7	2	12.50%
	5	1	6.25%
Rate your overall experience of attending medical school and why?	10	7	43.75%
	9	5	31.25%
	8	3	18.75%
	5	1	6.25%

62.50% of the respondents answered favorably towards the method of teaching received when attending medical school. This percentage is illustrated through the positive connotations associated with words such as enjoyed, excited, excellent, and collegiate, which were keywords in interviews regarding the first question in Table 1.0. Additionally, 100% of the answers rate it a five or higher out of a 10-point scale, with one being the lowest and 10 being the highest, as illustrated in Table 1.1 below. 93.75% percent of participants enjoyed the time spent in medical school, offering them a time of comradery and personal development, which is also illustrated by the frequent answer of a 10 rating in Table 1.1.

Through thematic analysis, the overarching theme regarding the application and preparedness for medical practice (see Table 2.0) was that a majority of the education acquired in medical school is essentially foundational rather than directly applicable to a physician's medical practice.

81.25% of the participants responded positively to the education they received and their preparedness for residency and medical practice. Additionally, 43.75% of physicians indicated positive responses regarding the applicability of medical school-acquired learning to their practice. However, the positive notions regarding the applicability of medical school related more to the emotional development and foundational education gained rather than medical school coursework entirely applying to a physician's daily practice.

As seen in Table 2.1, numerical calculations show that elevated ratings decreased significantly with the second set of ratings, as several participants rated this set with a number two. Additionally, the ratings decreased the most with the question of the applicability of medical school-acquired learning to medical practice.

Table 2.0 – Application and Preparedness of Medical Practice

Theme	Question	Commonality	Keywords	Example answers	Frequency	percentage
Medical curriculum as foundational knowledge of science rather than directly applicable to current medical practice	Rate your preparedness for residency and ultimately medical practice as a direct result of medical school and why?	Keywords	pretty/well success educated fundamental	I felt well **educated** and answered quite easily, and they always seemed quite pleased with my, uh, preparation.	13	81.25%
		Inadequate	unprepared hard transition	So I was completely **unprepared** for residency after coming out of medical school.	3	18.75%
	Specifically, rate the application of medical school-acquired learning to current (or recent) medical practice and why?	Applicable	foundation guiding training	**Foundation** of a building. I could still draw on things that I learned during medical school. I was able to relate to them quite a bit. That sort of allay concerns.	7	43.75%
		Somewhat	clinical last two years	Lot more applicable in the **last two years** when you're in your **clinical** years and you're in your rotations.	3	18.75%
		Inapplicable	little don't use irrelevant	I would say most of the information that I learned is pretty **irrelevant** to what I do now.	6	37.50%
	Rate your overall experience in providing medical care as a clinician and why?	Positive	love enjoy helping gratifying	Its very **gratifying**, just the ability to feel like you are **helping** someone.	12	75.00%
		Prepared	foundation Well trained	Medical school definitely established the **foundation**. Without that information I could never have gone forward.	3	18.75%
		Displeased	needs improvement	not negative. It's still not positive. But it's far from what it should be. Okay. Yeah.	1	6.25%

Question	Rating	Frequency	Percentage
Rate your preparedness for residency and ultimately medical practice as a direct result of medical school and why.	10	3	18.75%
	9	2	12.50%
	8	7	43.75%
	7	2	12.50%
	5	2	12.50%
Specifically, rate the application of medical school-acquired learning to current (or recent) medical practice and why.	10	2	12.50%
	9	3	18.75%
	8	2	12.50%
	7	2	12.50%
	6	2	12.50%
	4	1	6.25%
	3	1	6.25%
	2	1	6.25%
Rate your overall experience in providing medical care as a clinician and why.	10	4	25.00%
	9	7	43.75%
	8	4	25.00%
	6	1	6.25%

Table 2.1 – Rating of Application and Preparedness of Medical Practice

Theme	Question	Commonality	Keywords	Example answer	Frequency	Percentage
Understanding information in preclinical education was necessary for clinical rotations	From a clinician's viewpoint, what are the least necessary components of medical school?	Patient related care	Anatomy Clinical Physiology	**Clinical** rotations and the physiology courses.	11	68.75%
	From a clinician's viewpoint, what are the most necessary components of medical school?	preclinical	Review Basics Biochemistry Ethics Statistics	Rehashing of the **basic** sciences	10	62.50%
	In retrospect, are there specific classes or portions of classes that proved redundant or unnecessary?	Unable to recall	can't remember I don't know	I **can't remember**. If it was redundant or unnecessary, it sort of fell away in my memory	3	18.75%
		All necessary	No foundation needed	No. I would say that everything that I learned, I needed to know	6	37.50%
		basic sciences	Statistics Biochemistry	Some **biochemistry** was redundant. Some of the **statistical** classes were taught poorly	6	37.50%
	In the traditional curriculum, what year of medical school resonates with you as most essential and why?	3rd year	clinical applying foundation patient interactions	More **clinical** on the floor seeing patients using what you learned, **applying** it. You remember it better when you use	12	75.00%
		4th year	independent	More clinically involved in that area that you wanna pursue. **Narrowed** your search a little bit	2	12.50%

Table 3.0 – Components of Medical School Curriculum

The second thematic element presents itself through the decomposition of the essentials of medical school in order to establish comprehension of the duration and courses' effectiveness. As illustrated through Table 3.0, the overarching theme in answers was that although there was frequent rehashing of basic sciences, the complete understanding of pathophysiology is necessary in order to apply it to the most essential year in medical school: third year.

The third and final theme presented by the data related to redesigning the medical curriculum. Although 56.35% of respondents expressed a desire to diminish the duration spent on basic sciences and increase clinical exposure, there was an overall consensus that the barriers to shortening medical school would include vital components associated with developing a capable physician. As Table 4.0 illustrates, 56.25% of physicians voiced concern regarding the ability to sustain the quality of medical school with a condensed curriculum due to the inability of acquiring proper exposure to different circumstances and lack of adequate foundational knowledge which would adversely affect patient care.

Note that 31.25% of physicians believe medical school could be condensed, citing the existence of three-year medical programs. However, they also acknowledged these programs are highly discouraged. Additionally, 31.25% of respondents indicated that a significant barrier to shortening medical school is the inertia of the system, as altering the curriculum timeline would disrupt the July 1st model for residency entry.

Thus, according to most physicians, significant barriers remain to shorten medical school, including the need to establish foundational knowledge and the influence of long-standing traditions. Current medical school courses are essential for building a strong knowledge base for future learning. Furthermore, the existing timeline allows for the mental maturity and confidence required to develop as a physician. Ultimately, the results suggest that physicians believe the current courses and duration of medical school are effective.

Theme	Question	Commonality	Keywords	Example answers	Frequency	Percent
The capability of physicians to provide care would be impaired by shortening medical curriculum	If you were tasked with redesigning medical education, what would be your highest priority changes in the curriculum (and why)?	Greater patient experience	clinical	Early experience with those **rotations**. appropriate mentorship. In real life, you need to think and analyze all the information. That is something that is really hard to teach people to think. But it's not really memorization.	9	56.35%
			rotations			
			less basic			
		Current Curriculum	wouldn't change	I can really add too much to that. **Invaluable** experience	3	18.75%
			traditional curriculum			
			invaluable			
	Do you believe that condensing medical school is feasible without significant loss of quality?	Opposes	no	**I wouldn't** think so. I can't imagine that they could cut a lot out. I would think they'd have to put a lot in	9	56.25%
			wouldn't			
			don't			
			not			
		Believes	probably	I think medical schools **could** be three years	5	31.25%
			I do			
			yes			
			could			
		Unsure	maybe	Can I say I don't know? **Maybe**.	2	12.50%
			depends			
	What barriers would you anticipate in shortening medical school?	Insufficient education	pass tests	Amount of **information** needed to be conveyed. So much to learn and you get older each of those years which adds to your maturity and ability to manage things	11	68.75%
			information			
			skills			
			foundation			
		Disruptive	tradition	First barriers are those that are in charge. You would have to convince them that what you were doing was gonna be an improvement over what they've done for the **last 50 to 70 years**	5	31.25%
			July 1st model			
			inertia of system			

Table 4.0 – Redesigning Medical School

DISCUSSION

As the physician shortage continues to grow, researchers have explored potential solutions to increase the number of practicing physicians. Mowery identified medical school's length, rigor, and cost as significant deterrents to prospective students [2]. Similarly, Al-Shamsi highlighted the limited applicability of certain medical school coursework to physicians' daily practice, suggesting an opportunity to condense the curriculum [6]. However, the lack of clarity regarding which courses could be eliminated without compromising essential knowledge presented a challenge. The purpose of this study was to examine physicians' perspectives on the effectiveness of the length and content of medical school curricula. This study's findings indicated that most physicians interviewed oppose shortening medical school. Through qualitative analysis, three major themes emerged from the responses.

The first theme suggests that medical curriculum builds foundational knowledge of science rather than immediate practical application (see Table 2.0). The physicians emphasized that while the material learned in medical school is not always directly applicable to daily medical practice, it serves as a necessary foundation for residency training and lifelong learning. These findings align with Al-Shamsi's assertion that not all medical school knowledge is used in practice but contradict his suggestion that this warrants curriculum reduction [6]. The participants stressed that medical education should not be judged solely on its immediate applicability but rather on its role in preparing students for advanced medical training.

The second theme indicated preclinical education is essential for clinical preparedness. Participants noted that the first two years of didactic education provided them with the necessary knowledge to succeed in their clinical years (see Table 3.0). This finding contradicts Al-Shamsi's proposal to integrate preclinical and clinical years, as the traditional two-year preclinical and two-year clinical structure was widely regarded as effective [6]. The respondents affirmed that the foundational sciences learned during preclinical years were essential for their transition into patient care.

The third theme implied that shortening medical school risks educational quality (see Table 4.0). Although previous research [5] suggested that accelerated three-year medical school programs could reduce educational debt and expedite entry into clinical practice, the majority of physicians interviewed expressed concerns that such an approach would compromise medical education quality. While Mowery found that many prospective students are deterred by the cost and duration of medical training, the physicians in this study emphasized that reducing these barriers should not come at the expense of training adequacy [2]. Rather than shortening medical school, they advocated for maintaining the current curriculum length to ensure comprehensive preparation for clinical practice.

While the findings of this study offer valuable insights into physicians' perspectives on medical school curricula, several limitations should be acknowledged. First, the small sample size of 16 physicians limits the generalizability of these findings. Additionally, all participants attended medical schools in the East Coast and Midwest regions, which may have influenced their responses and reduced the diversity of educational backgrounds. This geographic concentration warrants caution when applying these results to a national context.

Furthermore, although some physicians identified the redundancy of basic medical sciences such as biochemistry and statistics, they still acknowledged the importance of these subjects in preparing for rotations. Future research could explore whether establishing uniform pre-medical education requirements across institutions could reduce redundancy and optimize the transition into medical school, potentially alleviating some concerns while maintaining educational quality.

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Experimental Analysis of BKZ and LLL Lattice Reduction Attacks on NTRUEncrypt

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ABSTRACT

The recent advent of quantum computers has brought rise to the need for quantum-resistant cryptography. Many of the cryptosystems we rely on today are believed to be extremely vulnerable to quantum attacks. This means that important information such as Social Security numbers, credit card details, and location data will be at significant risk of exposure to malicious actors. Lattice-based cryptography has shown to be a promising foundation for post-quantum cryptography because of the difficult underlying problems that are associated with lattices, such as the Shortest Vector Problem. In this paper, we explore this problem and its applications to NTRUEncrypt, a public key cryptosystem based on the use of multiplication and addition properties in polynomial rings.

INTRODUCTION

In 2016, the National Institute for Standards and Technology (NIST) began a call for submissions of quantum-resistant algorithms, aiming to select candidates for standardization [1]. Among these submitted algorithms is NTRUEncrypt (NTRU) of Hoffstein, Pipher, and Silverman [2]. Introduced in 1998, this public key cryptosystem relies on the difficulty of factoring large polynomials in a mixed polynomial ring into polynomials with very small coefficients in a specific quotient ring, a system rooted in principles of linear and abstract algebra. A public key cryptosystem is a cryptographic scheme involving key pairs which consist of a public key and a corresponding private key [3]. With appropriate adjustments, the NTRU can be formulated as a difficult lattice Shortest Vector Problem (SVP) that can potentially be solved through a lattice reduction algorithm.

Definition 1. A **lattice** L is defined as the set of all possible integer linear combinations of a set of linearly independent vectors $v_1, v_2, \ldots, v_n \in \mathbb{R}^n$. That is,

$$L = \{a_1v_1 + a_2v_2 + \ldots + a_nv_n : a_n \in \mathbb{Z}\}$$

This paper focuses only on integral lattices, where $v_i \in \mathbb{Z}^n$. A basis for L is defined as the set of linearly independent vectors that generates L. The dimension n of a lattice is the number of vectors in the basis [1]. The Shortest Vector Problem (SVP) is based around finding a shortest non-zero vector v in the l attice L.

The Shortest Vector Problem (SVP) is based around finding a shortest non-zero vector v in the lattice L. This is equivalent to minimizing $\| v \|$ for $v \in L$.

NTRUEncrypt

The NTRUEncrypt cryptosystem (NTRU) was developed in 1998 by Jeffrey Hoffstein, Jill Pipher, and Joseph Silverman. The NTRU works with polynomial rings, but the underlying difficult problem can be formulated as a lattice-based SVP problem [4].

POLYNOMIAL RINGS

A polynomial ring is denoted by $R[x]$, where polynomials in the ring have coefficients that are in the ring R. For example, $3x^2 + 4x + 1 \in \mathbb{Z}_5[x]$. We define $\frac{R[x]}{m}$ as the quotient ring of $R[x]$ by polynomial m, where $x^a = 1$ for $m = x^a - 1$ and $x^a = -1$ for $x^a + 1$ [4]. For example, consider $\frac{\mathbb{Z}_3[x]}{(x^2-1)}$. Let $f(x) = x^3 + 4$ and $g(x) = 3x^2 + x$. Then $f(x)g(x) = x + 1$.

KEY CREATION

The NTRU relies on the use of polynomial rings, utilizing multiplication and addition operations. The NTRU requires parameters (N, p, q, d), where $N \geq 1$ is a fixed integer, d is a random integer, and p and q are two moduli with $q > (6d + 1)p$. N and p must be prime, and gcd gcd(N, q) = gcd gcd(p, q) = 1.

Once the parameters (N, p, q, d) are chosen, the polynomial rings are created in the form

$$R = \frac{\mathbb{Z}[x]}{(x^N-1)}, R_p = \frac{\mathbb{Z}_p[x]}{(x^N-1)}, R_q = \frac{\mathbb{Z}_q[x]}{(x^N-1)}$$

The private key is created by forming $f(x) \in T(d + 1, d)$ and $g(x) \in T(d, d)$. $T(d + 1, d)$ presents a ternary polynomial with $d + 1$ positive 1 coefficients, d negative 1 coefficients, and the rest are zero coefficients. The, the inverse of $f(x)$ in R_p and in R_q are computed to form $F_p(x)$ and $F_q(x)$, respectively. The public key $h(x)$ is then obtained by

$$h(x) = F_q(x) \cdot g(x),$$

where multiplication is done in R_q.

ENCRYPTION

Definition 2. The **center lift** of a polynomial $f(x)$ in R_p is a polynomial $\hat{f}(x)$ whose coefficients are $-\frac{1}{2}p < f_i < \frac{1}{2}p$ and is congruent to $f(x) (mod\ p)$.

A plaintext message that is the center lift of a polynomial in R_p, $m(x)$, with coefficients between $-\frac{1}{2}p$ and $\frac{1}{2}p$, is created alongside a random polynomial $r(x) \in T(d, d)$. This is used to compute the ciphertext, $e(x)$ as

$$e(x) \equiv p \cdot r(x) \cdot h(x) + m(x) \ \ \text{in} R_q.$$

DECRYPTION

The decryption process begins by calculating $a(x)$ as

$$a(x) \equiv f(x) \cdot e(x) \ \ \text{in} R_q$$

Afterwards, $a(x)$ is center lifted to $\hat{a}(x)$ and used to compute $b(x)$ in R_p, which is equivalent to the original plaintext mes-

sage:

$$b(x) \equiv F_p(x) \cdot \hat{a}(x) (\text{mod } p) \equiv m(x)$$

LATTICE REDUCTION ALGORITHMS

Lattice reduction algorithms are algorithms designed to reduce an input basis B for a lattice L into a reasonably short and orthogonal basis for the same lattice. They are essential to solving the Shortest Vector Problem.

Definition 3. To measure the orthogonality of lattice basis vectors $B = \{v_1, v_2, \ldots, v_n\}$, we utilize the Hadamard Ratio, $H(B)$, which is defined as

$$H\left(B\right) = \left(\frac{\det \det(L)}{\|v_1\| \cdot \|v_2\| \cdot \ldots \cdot \|v_n\|}\right)^{\frac{1}{n}}$$

The closer $H(B)$ is to 1, the more orthogonal the basis is [4].

LLL ALGORITHM

The Lenstra, Lenstra, and Lovász (LLL) algorithm reduces an n-dimensional basis into a reasonably orthogonal (good) basis, making vectors as short and as orthogonal as possible [5]. Although we use it today as a tool for lattice reduction in cryptanalysis, its initial purpose was for factoring polynomials with rational coefficients. The LLL makes use of the Gram-Schmidt algorithm to generate an orthogonal basis $B' = \{v_1^*, v_2^*, \ldots, v_n^*\}$ corresponding to basis $B = \{v_1, v_2, \ldots, v_n\}$. Despite both B' and B having the same determinant, B' is not within lattice L due to receiving non-integer coefficients.

The Gram-Schmidt algorithm initiates the algorithm by generating the orthogonal basis $B' = \{v_1^*, v_2^*, \ldots, v_n^*\}$ for B. This is done by:

$$v_1^* = v_1$$

and

$$v_i^* = v_i - \sum_{j=1}^{i-1} \mu_{ij} v_j^* \text{ for } 1 \leq j \leq i-1$$

where

$$\mu_{ij} = \frac{v_i \cdot v_j^*}{\|v_j^*\|^2}$$

For every basis vector change, the following condition, the Lovász condition, is checked

$$\| v_i^* \|^2 \geq \left(\frac{3}{4} - \mu_{i,i-1}^2\right) \| v_{i-1}^* \|^2$$

If false, the vectors are swapped, and the Gram-Schmidt Algorithm is applied until the Lovász condition and the size condition,

$$\left|\mu_{ij}\right| \leq \frac{1}{2}$$

are met. Then, algorithm moves on to the following vector until there are no more, producing a reasonably orthogonal basis. The LLL relies on the parameter $\delta \in (0, 1]$ or the strictness of the reduction. A δ value closer to 1 results in a shorter, more orthogonal basis at the cost of a higher running time. We began with $\delta = \frac{3}{4}$, as is standard.

BKZ ALGORITHM

The block Korkine-Zolotarev (BKZ) lattice reduction algorithm is a variation of the LLL designed to be more efficient in computing orthogonal and short vectors in higher dimensions [1]. The BKZ works with a block of vectors. Instead of swapping individual vectors as the LLL does, the BKZ variant swaps blocks of vectors of length $\beta \in [2, n]$. The larger the block size (β), the better the results at the cost of increased running time [4].

The BKZ algorithm begins by LLL-reducing the input basis $B = \{v_1, v_2, \ldots, v_n\}$ a lattice. It then makes use of a local lattice L, which is generated by the orthogonal projection of B. This is defined by $\pi_i = L \rightarrow \text{span}(v_1, v_2, \ldots, v_n)^{\perp} \subseteq \mathbb{R}^n$. Each vector in π_i is calculated by $\pi_i(\mathbf{v}) = \mathbf{v} - \sum_{j=1}^{i-1} \mu_{ij} v_j$ [4]. This is essentially what the Gram-Schmidt algorithm repeatedly does for $1 \leq j \leq i-1$.

An enumeration algorithm is an algorithm designed to list the elements of a computational problem given a certain criterion. The BKZ makes use of an enumeration algorithm on the local lattice L to find the shortest vector and insert it into B, which is then LLL-reduced once more. This is repeated until the short vector found by enumeration is larger than the ith vector of B multiplied by the constant δ.

NTRUEncrypt CRYPTANALYSIS

By formatting the key recovery problem of NTRU as an SVP problem, the attacker can create a $2n$-dimensional lattice which is spanned by the M_h^{NTRU} matrix, given by

$$M_h^{\text{NTRU}} = \begin{pmatrix} I & H \\ 0 & q \cdot I \end{pmatrix},$$

where I represents the $n \times n$ identity matrix, 0 is an $n \times n$ zero matrix, and the rows of H are cyclical permutations of the coefficients of $h(x)$. This turns the NTRU key recovery problem into an SVP problem, and we can apply LL reduction to M_h^{NTRU}. Taking the first nonzero row vector of the reduced basis matrix gives the coefficients of the private keys, $f(x)$ and $g(x)$, up to rotation.

RESULTS

We implemented both the LLL and the BKZ algorithms in Python. Using our algorithms, we ran a few experiments on breaking a Python implementation of the NTRU in low dimensions n. The results are shown in Table 1 and Table 2,

respectively. We recall that δ is a parameter that determines the strictness of the reduction. We use the standard $\frac{3}{4}$ on. We use the standard 34 for BKZ reduction, and we compare $\frac{3}{4}$ and $\frac{9}{10}$ with pure LLL reduction.

LLL on NTRU			
n	Time (sec)	Hadamard Ratio	Delta δ
7	1.3	0.7	0.75
7	1.5	0.77	0.9
17	48	0.645	0.75
17	59	0.77	0.9
23	240	0.65	0.75
23	308	0.71	0.9

Our results verify past findings of how the LLL, even with a

Table 1: Average LLL reduction results on NTRUE

BKZ on NTRU			
n	Time (sec)	Hadamard Ratio	Block Size β
7	1.3	0.81	2
7	1.7	0.83	4
17	110	0.79	2
17	125	0.83	4
17	180	0.84	8
23	527	0.81	2
23	535	0.87	4
23	560	0.88	8

Table 2: Average BKZ reduction results on NTRU

higher δ, is much faster in computing a reduced basis and solving NTRU for low dimensions than the BKZ [4]. The BKZ, on average, takes more time to solve NTRU, but generates a higher quality basis, as seen with the consistently higher average Hadamard ratio. We also observed that even with a relatively low Hadamard ratio (0.5-0.6), the LLL would always correctly solve the NTRU. This could potentially indicate that, even for higher dimensions, the LLL is more suitable for breaking NTRU despite not producing a highly orthogonal basis like the BKZ. Alternatively, this could indicate that a stronger version of the BKZ is needed to efficiently break the NTRU.

DISCUSSION

We have explored effective lattice reduction algorithms and their applications to solving the SVP problem associated with the NTRUEncrypt. We described the techniques with which these algorithms can be used to break the cryptosystem and compared the efficiency of the LLL with the BKZ algorithm. We verified how, despite the high-quality basis return of the BKZ, the LLL might still be more efficient than breaking NTRU in higher dimensions.

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College of Science Student Spotlights

Meredith Sanders '27
ACMS & Psychology

How did you become interested and involved in this field of study? "I became interested in ACMS because I always enjoyed my math classes throughout middle school and high school, and I wanted to find a way to make math part of my career. I find ACMS as a major particularly unique because of its emphasis on using the specific material we learn in our courses to solve problems with real world implications. I have also decided to pursue a second major in psychology, as the two disciplines complement each other well. Although many people comment on how ACMS and psychology seem unrelated, I find that their pairing provides a strong foundation to understand human behavior through quantitative analysis and data-driven research methods."

What research have you conducted during your time in undergrad? "Since the fall of my freshman year, I have been a member of the Learning Analytics and Measurement in Behavioral Sciences (LAMBS) Lab. In light of the rapid development of artificial intelligence, I have assessed ChatGPT's accuracy in generating questions and solutions for AP Statistics education and other mathematical topics. This project was one I presented in November at the Ideas in Testing Conference in Chicago. Currently, I am working on two additional projects. The first involves analyzing AI usage policies across higher education institutions in both the United States and United Kingdom. The second uses web scraping to analyze the influence of AI on the labor market by analyzing the skill sets that are recommended in various job advertisements."

What is your favorite thing about research? "My favorite part of research, especially relating to my work in the LAMBS Lab, is having the opportunity to be on the forefront of advancements in technology and data science. Although there is a certain skepticism surrounding artificial intelligence, it is only going to become a bigger part of our lives. I enjoy knowing that I can help reduce uncertainty that people may have about its accuracy and overall role in society."

What are your career goals and how do you hope to incorporate what you have learned from research in your future work? "At this point in my education, my future career goals involve obtaining a PhD in quantitative psychology or data science. My research experience has been invaluable in preparing me to achieve these goals because it has taught me the necessary skills to collect and analyze data, as well as how to effectively present my findings to those who are unfamiliar with my work. Additionally, doing research has strengthened my creativity and problem-solving abilities, which are necessary for any type of career, academia or not."

Maggie Rakonick '25
Biochemistry & Bioengineering

How did you become interested and involved in this field of study? "I had the opportunity to perform scientific research in high school, and I loved it so much that I knew I wanted to join a lab at ND too. When I met with Dr. Blagg to learn more about the work in his lab, I was very impressed. He showed me that academic research is not just about getting grants but that real impactful work is being done right on our campus. There is currently no drug to prevent tau aggregation in the brain, so through his support and guidance, I was able to dedicate my research toward discovering a drug to treat Alzheimer's disease. I also love the grad students in my lab. They were all so welcoming and supportive of me as I learned new techniques so I knew I wanted to work with them to grow as a scientist. I did not know anything about Hsp90 or tauopathy when I joined the lab, but now I have learned so much and have found some lifelong friends in my labmates. My research experience has definitely been a highlight of my time at Notre Dame."

What research have you conducted during your time in undergrad? "I joined the Blagg lab at the beginning of my sophomore year. My project focuses on the interaction between 90-kDa heat shock protein (Hsp90) and its co-chaperone Aha1. This interaction has been linked to tauopathy and Alzheimer's Disease. I work alongside graduate student Kevin Catalfano to synthesize, purify, and evaluate small molecule compounds to block the binding of Aha1 to Hsp90 and prevent the tau aggregation. I have used many organic chemistry techniques and reactions like Suzuki couplings and azide-alkyne cycloadditions to create the molecules, and then we test the binding ability through Co-IP and a split *Renilla* luciferase assays. Once we complete our library of compounds,

we hope to patent our work to be used in future in vivo and clinical studies."

What is your favorite thing about research? "My favorite thing about science research is learning how the world works and using that knowledge to help others. Notre Dame teaches us to be a force for good, and I believe that research is my path to doing just that. I have always been a curious person and research allows me to dig deeper into new topics and never stop learning. I like working at the cellular level to identify what protein or what small molecule is behind the bigger issues. There are so many diseases that afflict people in our world who do not have the opportunity to help themselves or their loved ones to fight them. I want to use my time and skills toward helping them live a better life."

What are your career goals and how do you hope to incorporate what you have learned from research in your future work? "I plan to go to graduate school to receive my PhD and continue researching. I want to study diabetes and design new treatments to cure or prevent this disease. Though my current lab work does not focus on diabetes, it has given me valuable drug discovery experience, and I have developed my skills in many chemical and biochemical assays. Alzheimer's disease is also closely related to diabetes, so being in this lab has shown me the fluidity of science and how many levels there are to treating disease. I know science can seem tedious at times, but research has become a passion of mine over these past three years. I am excited to see where it takes me in the future."

Ivy Clark '27
Neuroscience and Behavior, Global Health, & Glynn Family Honors Program

How did you become interested and involved in this field of study? "I had really enjoyed systems neuroscience in my introductory neuroscience courses, so I knew I wanted to be involved in research that explored the structure and function of networks of neurons in the brain and their implications in the sensory signals received. When looking at labs in the neuroscience department at Washington University Saint Louis, I was really drawn to the Raman Lab because of their connection to olfaction and breath-printing as a diagnostic for infectious diseases such as tuberculosis. Through my minor in global health, I have found a passion in working with infectious diseases, and the Raman Lab allowed me to make the connection between systems neuroscience and the practical functions of my research in the global health realm."

What research have you conducted during your time in undergrad? "I was involved with student research teams through the Eck Institute of Global Health investigating loneliness post-pandemic in Saint Joseph County. I also work in the department of biomedical engineering at Washington University in Saint Louis in the Raman Lab, which is where I conducted the research I presented at SFN and COS-FURF. With the Raman Lab, I focus on olfaction in locusts, and the neuromodulation of specific olfactory responses. Here at Notre Dame, I am in the Koepfli Lab, working on a project investigating parasite load and hrp2 gene deletions in P. falciparum cases of malaria among pregnant women and infants in Burkina Faso."

What is your favorite thing about research? "I really enjoy seeing the real-life implications of research in health. Knowing that nearly all of our most groundbreaking medical advancements came from a research setting inspires me to push through long days in lab. I also have found some incredible mentors through my experiences in research, and I really value their partnership and guidance!"

What are your career goals and how do you hope to incorporate what you have learned from research in your future work? "I plan on taking a gap year before pursuing an MD/PhD in something related to infectious diseases—likely epidemiology or immunology! I hope to incorporate the collaborative skills I have learned to focus on developing strong partnerships with local communities when pursuing global health research."

Austin Dungan '26
Biological Sciences & Theology

How did you become interested and involved in this field of study? "I really liked science and math classes in middle school and high school, so I was able to narrow down my major selection to the STEM categories before applying to Notre Dame. After some thought, I chose the biology major on my application because of how seamlessly its content translated to the medical field. After taking two introductory biology classes and physiology during my first two years at Notre Dame, I was fascinated by what I learned. Through my studies, I discovered the more I learned more about the field of biology, the more

questions I had. This cycle of curiosity made it apparent that the biology major was the right choice for me."

What research have you conducted during your time in undergrad? "I joined the Wingert Lab during the fall semester of my sophomore year and began working on a project aimed at studying Friedreich's ataxia, a rare neurodegenerative disease. I have been researching Friedreich's ataxia since joining the lab, and I plan on continuing this research until I graduate. Our project uses a zebrafish model to study the disease as zebrafish share about 70 percent of DNA with humans and provide for quick production of large amounts of animals. With a frataxin loss of function model, our research hopes to understand the pathogenesis of Friedreich's ataxia with respect to organogenesis as a whole, specifically focusing on metabolic tissues such as the kidney, heart, liver, and pancreas."

What is your favorite thing about research? "My favorite part of my project is its potential to help people in the real world. By actively participating in research, whether you choose biology or any other field, you have the opportunity to make discoveries and advancements that could benefit many lives. In my research specifically, the end goal is to make discoveries that would lead to potential therapies for patients with Friedreich's ataxia, a goal that makes my involvement in the lab infinitely rewarding."

What are your career goals and how do you hope to incorporate what you have learned from research in your future work? "After graduating from Notre Dame, I plan on attending medical school and becoming a physician. Among many benefits, my research has sharpened my critical thinking skills and given me a better understanding of neurodegenerative disease pathology, a subset of diseases that I will likely encounter in clinical practice. Beyond academic skills, researching a rare disease has shown me the importance of focusing our efforts on both those who suffer from rare and often neglected pathologies and those with more prevalent conditions."

Thomas Reimer '26
Chemistry

How did you become interested and involved in this field of study? "When I was a kid I had a copy of the book *Elements: A Visual Exploration of Every Known Atom in the Universe*, and I remember flipping through it and reading about the different elements, their properties, and their uses. I also really enjoyed taking things apart and reassembling them to see how they worked, and chemistry is the science of doing this on a small scale, so I quickly grew fond of it."

What research have you conducted during your time in undergrad? "I started in the Fu Lab, where I worked on quantifying nonspecific-protein fouling to a biosensor using a quartz crystal microbalance and synthesizing antifouling molecules to prevent said biofouling. This project showed me how different disciplines of chemistry can be brought together to solve problems. As for my research, I had to use principles and techniques from bio-, organic, and analytical chemistry. I then worked in the Hashmi Lab at Universität Heidelberg in Germany over the summer, funded by the IRES program. My project dealt with probing and expanding the scope of a gold-mediated photocatalytic cyclization used to create indolines from anilines. I then returned to Notre Dame and joined the Ashfeld Lab, where I now work on developing new organic methodology, mostly in the field of C-H functionalizations. Additionally, I work on the synthesis of PROTACs targeting DYRK1A, a protein with important roles in Down syndrome-linked neurodegeneration, Alzheimer's disease, and cancer."

What is your favorite thing about research? "My favorite part of research is that it lets you use your mind and hands to build things that can hopefully have an impact on others. It's akin to a puzzle, where the longer you take and the more effort you put into it, the more likely you are to stumble upon the 'correct solution.' However, in the case of research, the 'correct solution' isn't simply a nice picture, instead, it's a piece of knowledge that can actually be used by you and others to fix problems in the future."

What are your career goals and how do you hope to incorporate what you have learned from research in your future work? "I plan on pursuing a PhD in organic chemistry, focusing on total synthesis. However, I also have a lot of interest in chemical biology, so I want to pursue a career that integrates organic chemistry and synthesis with the manipulation of biological systems, likely in the pharmaceutical industry. I feel that my research thus far has prepared me for this, as I've spent time working with biologics and performing organic syntheses, but there is always more to learn."

Mackenzie Kelleher '25
Neuroscience and Behavior & Science and Patient Advocacy

How did you become interested and involved in this field of study? "I first became interested in studying cancer biology during the fall of my freshman year. I was a student in Dr. Zach Schafer's Biology I: Big Questions Module called 'Natural Selection: The Reason Why We Haven't Cured Cancer?' I was fascinated by its topic of natural selection at the cellular level during tumorigenesis. I learned the crucial role that research plays in bettering human health, starting by elucidating the molecular basis of disease. We read primary scientific literature and analyzed experimental data in class, and I found this process really exciting. I reached out to Dr. Schafer at the end of the fall semester, expressing an interest in his research. I officially started working as an undergraduate researcher in the Schafer Lab at the start of my sophomore year."

What research have you conducted during your time in undergrad? "I have worked as an undergraduate researcher in the Schafer Lab since August 2022. Our lab has an overarching goal of understanding the mechanisms that allow cancer cells to survive during metastasis. We have a particular interest in cell death pathways, tumor cell metabolism, and how the regulation of metabolism and cell death intersect. My research project has focused on an iron-dependent type of cell death called ferroptosis. We discovered a novel and specific marker to detect ferroptosis: the reducing reagent-resistant dimer of transferrin receptor 1 (TfR1), which we termed the '3R dimer.' In addition to my work at Notre Dame, I spent a summer conducting research at Memorial Sloan Kettering Cancer Center. There, I spent 10 weeks researching leptomeningeal metastasis (LM), the spread of cancer cells to the cerebrospinal fluid-filled coverings of the brain and spinal cord. The aim of my project was to characterize interactions between leptomeningeal cancer cells and fibroblasts of the pia mater."

What is your favorite thing about research? "My passion for research is ultimately driven by a desire to improve patient lives. Therefore, my favorite thing about research is knowing that the questions we investigate to understand basic mechanisms of disease could ultimately lead to the discovery of life-changing therapies for patients. I also love the collaborative nature of scientific research. In April 2024, I had the opportunity to attend and present my research at the American Association for Cancer Research Annual Meeting. Witnessing over 22,000 people from all over the world come together in pursuit of scientific progress was an inspiring example of collaboration."

What are your career goals and how do you hope to incorporate what you have learned from research in your future work? "After my graduation this May, I will begin my graduate studies in the Harvard University Division of Medical Sciences PhD Program in Biological and Biomedical Sciences (BBS). After graduate school, I hope to pursue a research career in industry and am particularly interested in biotechnology. I am in the Science and Patient Advocacy Minor here at Notre Dame which has motivated me to work as a scientist at a biotechnology company that focuses on rare cancers or other rare diseases."

Luke Lagunowich '26
Computer Science & ACMS

How did you become interested and involved in this field of study? "After my first semester at Notre Dame, I decided to be a computer science major. However, when I began my sophomore year, I knew I wanted to expand my academic horizons further into a related but also differentiated field of study, so I reached out to Dr. Daniele Schiavazzi in ACMS about research. Applied mathematics and statistics has many applications in the cutting-edge area of artificial intelligence, so I believed leveraging my computer science background within a field of statistical research would be beneficial to my academic journey. The research that I am part of has broad applications within robotics and epidemiology. I believe that is the beauty of applied mathematics and statistics. It is everywhere! Since then, I have become further interested in the subject and have added a supplementary major in ACMS."

What research have you conducted during your time in undergrad? "Since joining Dr. Daniele Schiavazzi's research group, I have explored and researched simulation-based inference and normalizing flows. Normalizing flows are a class of generative models that can represent complex probability distributions through a series of parametrized, invertible transformations of a simple base distribution. Normalizing flows are traditionally used in generative modeling and density estimation. My research leverages normalized flows with various deep-learning-based conditioning operators for state estimation tasks in robotics and epidemiology. We are exploring further applications in parameter estimation and uncertainty quantification, and we are implementing new

training methods to optimize the probability path between distributions. This research could have interesting impacts on modeling and understanding the dynamics of an epidemic."

What is your favorite thing about research? "What I enjoy most about research is that the problem-solving process never ends. Once one question is answered, another appears, particularly when the research is performed in a team setting. Different perspectives can raise new areas to explore or concerns to address. Once research begins, it never truly ends. As someone who enjoys problem-solving, research is the gift that keeps on giving."

What are your career goals and how do you hope to incorporate what you have learned from research in your future work? "After graduation, I plan on entering the work force. I hope that my research and skills learned from the process will benefit my career. From a technical perspective, a deeper understanding of statistical methods should hopefully prove useful in a variety of applications. Moreover, the skills developed from partaking in research are boundless. I hope to also apply these new problem-solving skills in my career. Eventually, I plan to pursue a MS and PhD and, hopefully, teach and perform research at a university like Notre Dame."

Lara Sozer '25
Neuroscience and Behavior

How did you become interested and involved in this field of study? "Since I was young, I was always interested in understanding the processes behind people's behavior. It is fascinating to me how people can be so different from one another despite us all having brains with similar structures and shapes. We take in information differently, feel differently about it, and respond to it differently. Through the classes I have taken here, I learned this could stem from cognition, which led me to explore the different ways one could analyze cognition in the field of neuroscience research."

What research have you conducted during your time in undergrad? "I have participated in hands-on research while working in the Family Studies Lab directed by Dr. E. Mark Cummings, which conducts state-of-the-art research on family functioning and relationships. While working there for nearly four years, I primarily recorded and assessed the meetings with families that participated in the lab's studies. However, I also gathered and organized the data for these projects as I became very acquainted with the Family Interactions Coding System (FICS), an observational coding system used to study family interactions. In my junior year, I even had the opportunity to use research from the lab to run a cognitive study under the supervision of Dr. E. Mark Cummings to graduate with honors in my major. My study specifically aimed to use the Family Study Lab's research on communication interventions to study the possible correlations that could exist between a family's perception of a conversation and the more objective evaluations of their conversations produced by FICS. This experience familiarized me with the challenges and skills involved in leading and presenting a research project. I have specifically presented my research at the 2024 Fall Undergraduate Research Fair (FURF) at the University of Notre Dame. A multitude of my courses also have granted me many research opportunities, including getting a chance to run both electroencephalograms and transcranial magnetic stimulation and working with databases for genomes."

What is your favorite thing about research? "The growth that comes from research. Through my time working in the Family Studies Lab and working on my thesis, I have improved in many skills and also picked up a few new ones. Simply working in the lab got me acquainted with a variety of programs and study methods and I have only learned more by writing my thesis. With every semester that passed, I felt as though I learned something new and grew as a person. It is a very satisfying feeling. I hope in the future, I will not only continue learning but that my research can teach others something new as well."

What are your career goals and how do you hope to incorporate what you have learned from research in your future work? "After getting my bachelor's in neuroscience and behavior, I hope to spend 1-2 years working on hands-on neuroscience research to not only continue building up my skillset but also narrow down my research interests. Following this, I intend to get a PhD in neuroscience, specifically computational neuroscience. Then I intend to get a career in machine learning (ML) research, specifically, research focused on cognition. My research here has given me a head start in knowing what to expect in these future workplaces. It is through my research here that I was able to begin developing my skills, join a lab, present my research, even run EEGs. I am more motivated than ever to continue following my passion for neuroscience research."

Brian Ram '25
Biological Sciences & Psychology

How did you become interested and involved in this field of study? "Mental phenomena including cognition and emotion are fundamental components of the human experience. I was interested in exploring these facets of the mind as they inherently shape our consciousness and perception of the world around us. Conducting clinical research appealed to me because it allows for the direct application of scientific thinking and investigation to patient populations. I got involved by learning more about dysregulations in mood concerning anxiety and depression and sought out research opportunities that would enable me to examine these mental processes further. The increasing prevalence of neuropsychiatric disorders warrants greater research effort and awareness for individuals struggling with a mental health diagnosis, which ultimately led to my involvement in this field of study."

What research have you conducted during your time in undergrad? "At the University of Notre Dame, I am a research assistant in the Cognition and Emotion Lab. As part of this team, I investigate the cognitive correlates of mental health disorders, primarily focusing on the hopelessness theory of depression. Other areas of research as part of this group include embodied cognition, real and minimal group biases, and cognitive representations of illness. As a student in Copenhagen, Denmark, I collaborated with the Danish Cancer Institute to analyze the psychological factors associated with resilience in primary cancer caregivers in the face of adverse psychological outcomes including anxiety, depression, and stress. Additionally, I am a research assistant at St. Jude Children's Research Hospital exploring the relationship between inflammation and family environment, the impact of illness perceptions on emotional health, and health behaviors and attitudes regarding vaping in survivors of pediatric cancer."

What is your favorite thing about research? "My favorite thing about research is that it provides an opportunity for intellectual curiosity and growth beyond the traditional classroom environment. Being part of a team and doing meaningful work that changes the lives of patients with physical or mental illness draws me back into the lab again and again. Regarding psychological research, I enjoy understanding how to best define and measure latent constructs, as well as their connection with biological processes. The exploration of the mind and body as it relates to disease is incredibly interesting and continues to be a focal point for me as a researcher."

What are your career goals and how do you hope to incorporate what you have learned from research in your future work? "I intend to pursue a career in medicine with a significant research component. My knowledge of mental health will enable me to better understand and treat patients who experience anxiety, depression, or stress as a result of living with illness. Treating others with empathy and compassion requires a deep understanding of what it means to be human from the cognitive, behavioral, and emotional perspectives. Ultimately, I hope to promote the integration of psychology in healthcare and advocate for the destigmatization of mental illness on my journey to becoming a physician."

Joseph Draganowski '27
Biology & Program of Liberal Studies

How did you become interested and involved in this field of study? "I have had a fascination with the natural world as far back as I can remember. Throughout my childhood, whenever I was not outside fishing or looking for insects, I would be reading science books, especially about animals. Animals, and insects in particular, were always my favorite, and so when I started undergrad, a biology major was the obvious choice. I have never regretted it—each of the biology classes that I have taken has helped me not only know more about the living things that I love but to appreciate their beauty and diversity in new ways, and each has opened up new paths of inquiry for me to follow in the future.
After I came to Notre Dame, I added a major in the Program of Liberal Studies (PLS), a seminar-based major on a Great Books curriculum. I originally started studying PLS because I wanted to spend more time engaging with great works and ideas in theology, philosophy, and literature, and the major has helped me do not only that, but also develop a deeper love for the human search for truth through discourse, thought, and reason. Overall, I find that it complements my study of biology well and helps me formulate my ideas better and approach problems from different perspectives."

What research have you conducted during your time in undergrad? "Last summer I spent ten weeks doing the UNDERC Track 1 program at Notre Dame's ecology field station in northern Michigan, during which I helped design and perform a research project on how the presence of roads

affects insect communities in forests at various distances from those roads. Although we expected to find fewer insects near roads, our results showed that some flying insects were actually found in higher numbers along the roadways that we studied. The reasons for this are still unclear, and so I hope to be able to expand on this project at some point in the future. This past year, I have been working with the Coverdale Lab, which studies grassland ecology. I started by doing insect identification as part of a study looking at how different plant community compositions affect communities of other prairie organisms, including insects. However, I have just begun to work on a different project in this lab, looking at the effects that reintroducing megaherbivores will have on the plant communities of a Kenyan savanna. I also hope to develop a related project of my own within the lab and carry it out as a senior research thesis. Besides these research projects, I have also been working with the insect collections in the Museum of Biodiversity for a few semesters now. Here I have been able to channel my previous experience with collecting and studying insects towards identification and organization work on many different groups—my favorites so far have been some big beetles from Trinidad. I am also improving my identification skills and my general expertise with insects, which I hope to put to good use in future research projects."

What is your favorite thing about research? "One of the things that I love most about research, and really one of the reasons that I do research in the first place, is being out in the field, collecting data and making observations, and just immersing myself in nature. I study biology because I love learning more about the vast array of creatures that inhabit our planet, and so my favorite part is when I actually get to experience them firsthand, especially when I find something new to increase my awe and delight. By that token, I also love seeing the results of my research because I get to learn new things about the organisms I am studying, maybe even things nobody knew before. That being said, I also get a strange satisfaction from the simple event of seeing my results come out at the end of a project. Data entry and data analysis are not my cup of tea, but no matter how long or tedious they are, it always just feels good to finish and have something to show for it, and that, I suppose, is the part about research that keeps me going after my favorite part, being out in the field, is over."

What are your career goals and how do you hope to incorporate what you have learned from research in your future work? " I am hoping to go on to graduate school to get a Ph.D. in ecology with a focus in entomology, doing research on how different species depend on each other within an ecosystem. The ways in which seemingly unrelated species have essential connections to each other, influencing each other's lives and evolution, fascinates me, and so I plan to center my research around uncovering and understanding more of these connections. I would like to continue to do research in this vein after I get my degree, and so I will probably try to take on a research position at a university. Research aside, however, I do want to teach, using my research experience to kindle my love for insects and biodiversity in others so that even more people can appreciate the beauty of the vast array of creatures all around us."

Konrad Czyzewski '26
Honors Biological Sciences with a Concentration in Biomedical Sciences

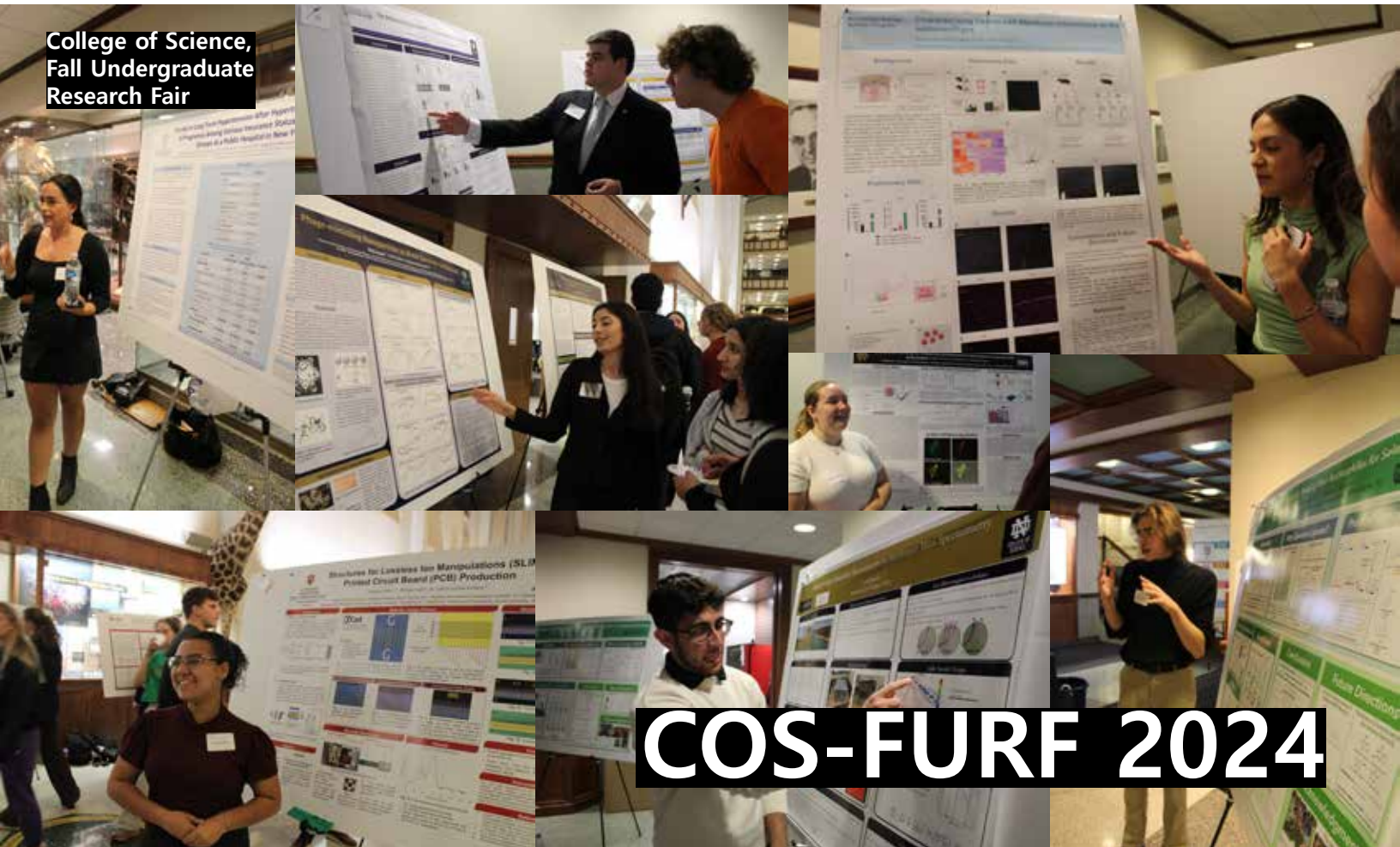
How did you become interested and involved in this field of study? "I have always been fascinated by rogue behavior, whether in basic biology or in humans. However, my interest in cancer biology first grew during my freshman year when I enrolled in Natural Selection: The Reason Why We Haven't Cured Cancer?, a course taught by Dr. Zachary Schafer. This class provided an in-depth exploration of natural selection at the cellular level during tumorigenesis, highlighting the evolutionary pressures that drive cancer progression and therapeutic resistance. The complexity of cancer's adaptive mechanisms captivated me and pushed me in a direction to pursue research that seeks to unveil these intricate metabolic processes. I sought research opportunities in Dr. Schafer's laboratory, where I was introduced to basic research in cancer. Investigating cellular metabolism and mechanisms of non-apoptotic cell death allowed me to explore fundamental aspects of tumor biology, which has helped me realize that I would like to pursue it as a career."

What research have you conducted during your time in undergrad? "During my undergraduate studies, I have conducted extensive research on cancer biology, focusing on the molecular mechanisms that drive tumor survival, metabolic adaptation, and immune evasion. My work in Dr. Schafer's laboratory has primarily centered on understanding the role of mitochondrial enzymes in ferroptosis, an iron-dependent form of cell death characterized by lipid peroxidation. Specifically, I have investigated aconitate decarboxylase 1 (ACOD1) and its regulation of reactive oxygen species (ROS) and ferroptosis sensitivity in extracellular matrix (ECM)-detached cancer cells. My research has provided insights into ACOD1's role in oxidative stress modulation and its potential contribution to resistance against PD-L1 therapy. In addition to my work on ACOD1, I was awarded a College of Science Summer Undergraduate Research Fellowship to study phosphoglycerate mutase family member 5 (PGAM5), a mitochondrial phosphatase, and its involvement in mitophagy and non-apoptotic cell death pathways. My findings demonstrated that PGAM5 expression is dynamically regulated across the cell cycle, with downregulation occurring under ECM-detached conditions—suggesting a survival mechanism

in anchorage-independent cancer cells. Beyond my work in molecular oncology, I have participated in translational and clinical research projects. At Weill Cornell Medicine, I studied Rhinovirus infections and asthma polymorphisms associated with COVID-19 in pediatric patients, applying a translational research approach to respiratory disease pathology. Additionally, I contributed to a study published in *Cureus Journal of Medicine*, 'Focal Crescentic Glomerulonephritis Following COVID-19 Viral Vector Vaccination.' My role included reviewing hospital records, analyzing biopsy data, and conducting literature reviews to evaluate vaccine-associated autoimmune responses. Additionally, I conducted research on rare pediatric conditions, including Rectal High-Grade Neuroendocrine Tumor and Transaldolase Deficiency, reinforcing my commitment to advancing knowledge in disease pathology and clinical translation."

What is your favorite thing about research? "Beyond the skills that research has helped me develop, my favorite aspect of research is the people I collaborate with. Scientific discovery is inherently a collective effort, and the exchange of ideas with peers, mentors, and professors fosters an environment of critical thinking. The weekly lab discussions, problem-solving, and shared excitement over experimental breakthroughs create an atmosphere that enhances both my personal character and actual scientific achievement. Engaging in research has allowed me to develop a deep appreciation for mentorship, as I have benefited immensely from the guidance of experienced physicians and scientists who have shaped my approach to answering scientific questions. Additionally, working within a group of diverse minds has reinforced my ability to communicate complex scientific concepts effectively and answer questions from different perspectives. The relationships formed in the lab, built on mutual curiosity and shared goals, are key in driving scientific progress and have further motivated my aspiration to contribute to biomedical research."

What are your career goals and how do you hope to incorporate what you have learned from research in your future work? "My ultimate career goal is to pursue an MD or an MD/PhD in cancer biology, enabling me to integrate both scientific research and clinical practice to develop therapeutic strategies for cancer treatment. Before attending medical school, I intend to pursue graduate studies to deepen my expertise in cancer biology and research. By engaging in advanced training, I will strengthen my ability to translate laboratory discoveries into clinical applications. My research experiences have provided me with a strong foundation in cancer metabolism, immune evasion, and targeted therapy resistance. These are critical areas that I aim to explore further in medical and clinical oncology. I am particularly interested in developing therapies that target tumor metabolic pathways and improve treatment efficacy while minimizing resistance mechanisms. By leveraging my research background and clinical training, I hope to contribute to advancements in precision oncology and patient-specific treatment approaches."



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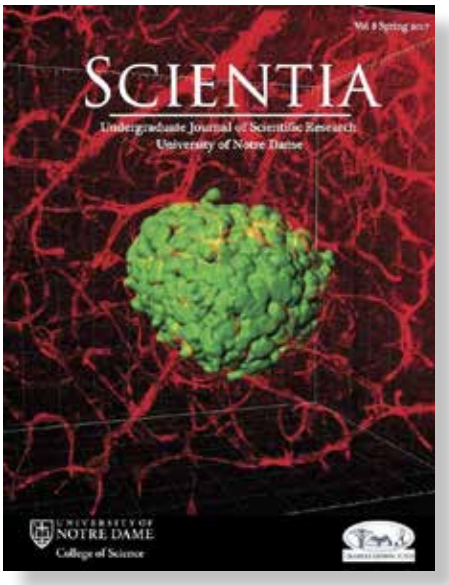
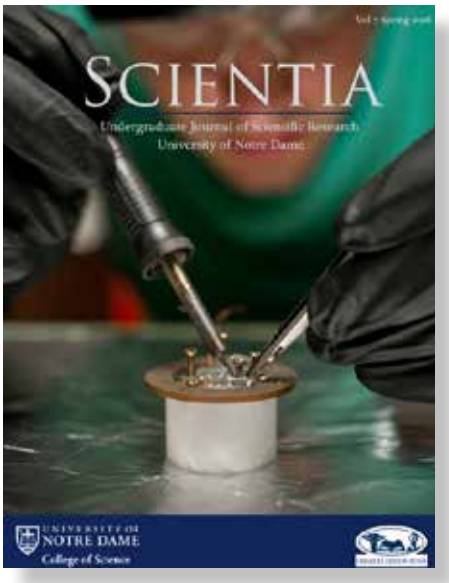




TALK SCIENCE

September 25, 2024

Dr. Nathan G. Swenson

"Disentangling the Drivers of Tree Coexistence and Biodiversity from the Temperate Zone to the Tropics Through the Lens of Neighborhood Encounter Rates"

Senior Joshua Moeller

"Effects of Ethanol Exposure on Zebrafish Embryonic Nephron Development"

October 30, 2024

Dr. Crislyn D'Souza-Schorey

"Message in a Bubble: Understanding How Tumor Cells Communicate"

Senior Julian Kaufmann

"Symmetric, Optimization-based, Cross-element Compatible Nodal Distributions for High-order Finite Elements"

November 20, 2024

Dr. László Forró

"How to Do Scientific Research with Responsibility"

Junior Christine Hruby

"Monitoring Water Quality in UNESCO's Dublin Bay Biosphere"

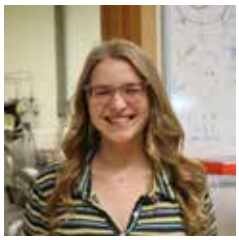
February 12, 2025

Dr. Emily Tsui

"Quantum Dots for Renewable Energy Applications"

Senior Emma Laboe

"Thermoelectric Behavior in Quantum Materials: Characterizing the Kagome Metal $TmMn_6Sn_{6-x}Ga_x$"



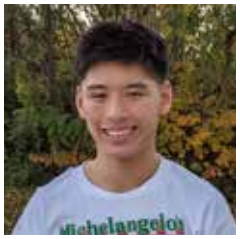
March 19, 2025

Dr. Ryan Sensenig

"Managing grasslands to capture carbon: interactions between fire and grazing"

Junior Michael Li

"Binary Classification of Dermoscopic Lesions via Bayesian-Optimized Ensemble Convolution Neural Networks"



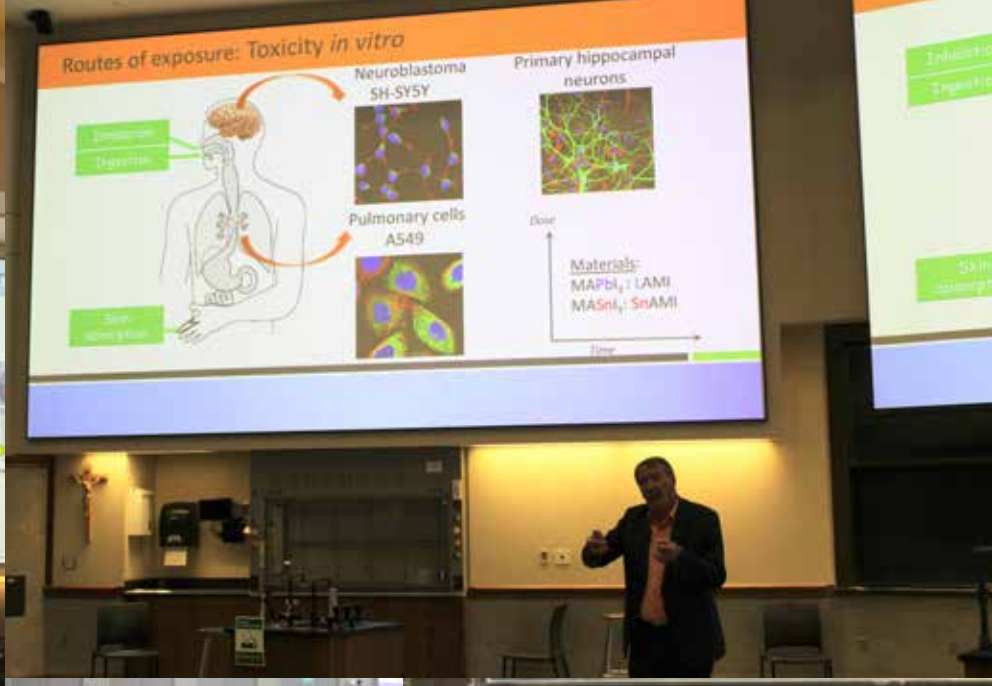
April 9, 2025

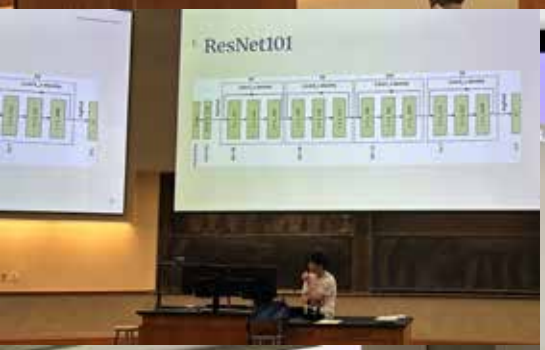
Dr. Ana Lidia Flores-Mireles

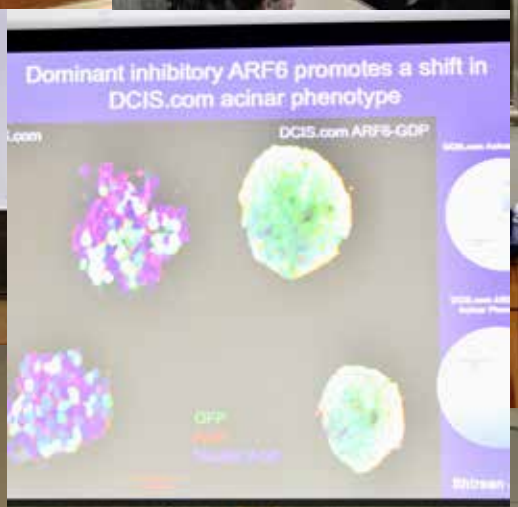
"How to develop therapies for the most common hospital-acquired infection"

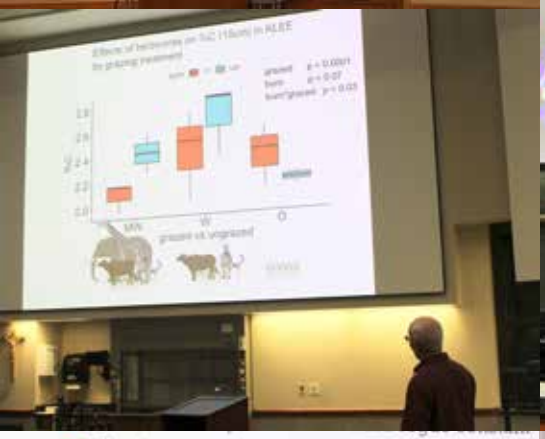
Sophomore Charles Sander

"Investigating the Role of the Coxsackie and Adenovirus Receptor in Neuronal Development and Synaptic Function"



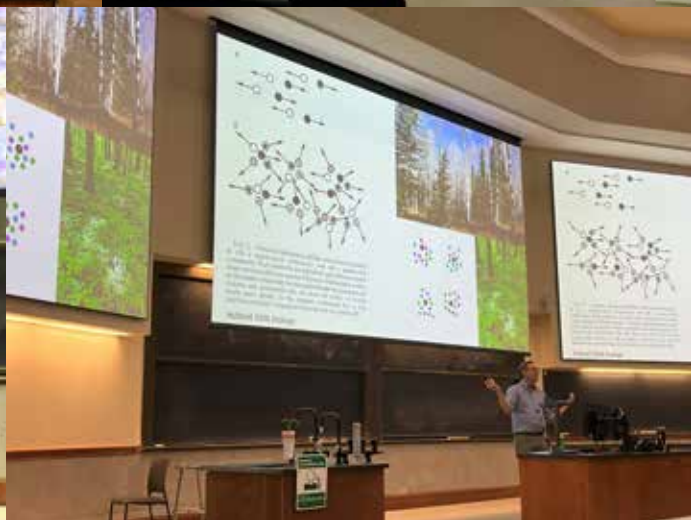






- Calculate mass matrix condition number
- Compare with existing distributions

$$\Lambda : \bar{\xi} \mapsto \max_{x \in \Omega} \sum_{i=1}^{n} |\ell_i(x; \mathbb{N}_{\bar{\xi}})|$$



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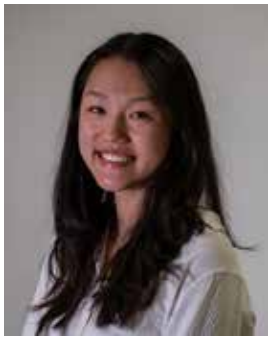

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