Narratives of Undergraduate Research, Mentorship, and Teaching at UCLA

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Abstract: This work describes select narratives pertaining to undergraduate teaching and mentorship at UCLA Chemistry and Biochemistry by Alex Spokoyny and his junior colleagues. Specifically, we discuss how individual undergraduate researchers contributed and jump-started multiple research themes since the conception of our research laboratory. This work also describes several recent innovations in the inorganic and general chemistry courses taught by Spokoyny at UCLA with a focus of nurturing appreciation for research and creative process in sciences including the use of social media platforms.

Keywords: undergraduate research, mentorship, inorganic chemistry, boron clusters, chemistry appreciation, science communication, science literacy, chemistry Twitter

Introduction:

The Spokoyny laboratory opened its doors at UCLA on August 1, 2014; through the past six years, we have been actively engaged in creating a world-class research environment and infrastructure to fully support our scientific and teaching needs.

As a UCLA alumnus and having conducted undergraduate research in chemistry, Spokoyny feels strongly about creating more of such opportunities for the next generation of UCLA undergraduates. As a result, in less than six years our group has mentored and graduated over 30 undergraduate students and we plan to continue to provide our laboratory as a safe and interactive resource for those who are willing to commit and learn more about experimental chemistry. Furthermore, our policy in selecting undergraduates has always been GPA-blind as we are convinced that we simply cannot close the doors on those who are less fortunate in their academic achievements at such an early stage. We mentor and guide these students on an individual basis, where we discuss their career goals and objectives and how their research involvement can advance these specific goals as well as their general learning. We believe that no matter what these individuals decide to do in their future, their exposure to a true research environment will be able to open their eyes to the world of scientific enterprise, which simply cannot be adequately communicated in any traditional lecture course offered at the college level. This approach has already bred tremendous success: over 20 of our undergraduate researchers are co-authors on research manuscripts published or currently submitted for publication. These individuals represent a very diverse group consisting of first generation college students, immigrants, athletes, and military veterans coming from many places across the United States and the World and covering various socio-economic backgrounds.

Importantly, our ultimate goal is not to create a future army of chemists, but rather to provide each individual a tailored experience of what hypothesis-driven laboratory research is all about. By doing so, we hope to contribute to educating future generations on the critical impact of academic science and fundamental research in our society, disproving the myth among some that we (academics) represent an elitist class of individuals fundamentally out of touch with the real world. It happens often that undergraduate researchers are the "unsung heroes" in academic laboratories and their contributions tend to be dismissed and overlooked. To combat this attitude, below are presented 18 short narrative profiles of undergraduate students who worked in our laboratory and contributed immensely to the science and human interactions in our laboratory. The remainder of this work highlights some teaching innovations and philosophies that Spokoyny and his colleagues have implemented over the past several years.

Narratives of Undergraduate Researchers:

Figure 1. A cohort of undergraduate researchers in the Spokoyny laboratory who worked in the group circa 2014-2016. Top: Simone Stevens (left), Alice Phung (center), Alejandra (Ali) Gonzalez. Bottom: Yanwu Shao (left), Elamar Moully (center), Vinh Nguyen (right).

As a high school student, Simone Stevens (Figure 1) was convinced that architecture was her sole calling in life. It was not until she took her first chemistry class that she quickly realized the world was revolving largely around this fundamental subject. At first, she had a difficult time navigating the next steps in her education as she was a first-generation college student. Joining a research lab was an invaluable experience that helped translate theories from the classroom setting to hands-on work and its potential future applications. While a member of the Spokoyny Lab at UCLA, Stevens worked on the synthesis of B-bromo-carboranes that were subsequently used as a versatile electrophile-based platform for new Pd-catalyzed cross-coupling chemistry (Figure 2) [1]. Not only did she learn useful laboratory techniques, but more importantly, how to begin the research process. This set of skills has helped Simone in every endeavor since, including working to develop food chemistry at Beyond Meat during her first job after graduating college. Stevens is currently finishing a Master's degree in Mechanical Engineering at San Diego State University with an emphasis in materials—perhaps a realistic blend of architecture and chemistry after all. She enjoys tuning chemical and structural components to achieve preferred properties and hopes to use this in the development of new smart materials in her future career.

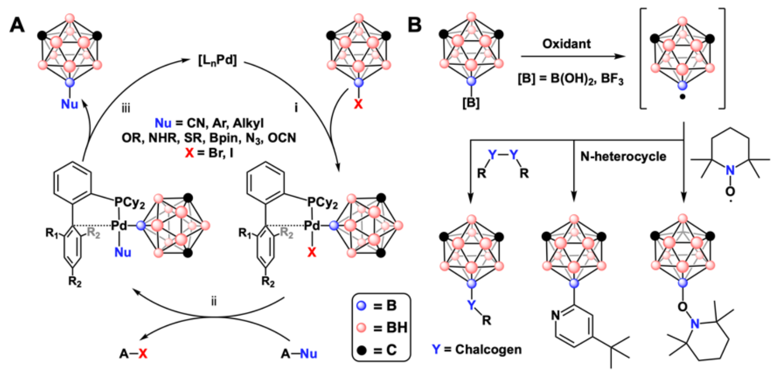

Figure 2. New carborane chemistry developed with a contribution of UCLA undergraduates. A. Pd-catalyzed cross-coupling chemistry and B. radical-based approach towards carborane functionalization at boron vertices. Steps i-iii represent oxidative addition, transmetallation and reductive elimination, respectively.

In her final year as an undergraduate at UCLA, Alice Phung (Figure 1) was on a pre-pharmacy path, working as a pharmacy technician at the nearby Veteran's Affairs (VA) facility. She wanted to explore other career paths open to a biochemistry major such as herself, so during her last term, she sought to join a laboratory in the Chemistry and Biochemistry Department. As a senior who was one month away from graduation, laboratories were generally unwilling to allow her participation. Despite this, she was hired by the Spokoyny group as a lab assistant. Alice was the first undergraduate student to join Spokoyny's laboratory as she had enlisted on the first day of his arrival to UCLA in August of 2014. Needless to say, she has seen and experienced all aspects of setting up a brand new chemistry laboratory and helped the group tremendously throughout the process. Emboldened by the sense of community and the dedicated work ethic the group instilled, and not discouraged by dealing with a multitude of chemistry vendor sales representatives, she chose to remain in research and continue to create new molecules that previously did not exist. Currently, Alice is a Ph.D. student in the Chemistry Department at UC Davis where she is studying organometallic synthesis in the laboratory of Prof. Philip Power. Recently, Alice and co-workers published a manuscript disclosing a new process featuring metathesis between metal-metal triple bonds [2]. She is also continuing to explore her multifaceted hobbies which include baking, soap making, and creative fiction writing.

Prior to attending college, Alejandra Gonzalez (Ali, Figure 1) was unsure of what she wanted to do as she did enjoy many academic subjects in both the arts and sciences. Upon enrolling at UCLA, Ali joined a professional Chemistry fraternity chapter (Alpha Chi Sigma), which allowed her to make many important connections and push to pursue her interests in chemistry. She enrolled in Spokoyny's inorganic chemistry course and after discovering her passion towards exotic molecules, joined his lab where she focused on developing the syntheses and exploring the materials properties of luminescent compounds. Under Spokoyny's mentorship, Gonzalez was a part of a UC LEADS program and gained skills in both materials research and organic chemistry. Ali worked as a part of a team (together with Alice Phung) that was able to successfully synthesize and characterize unique, blue phosphorescent d^8 metal complexes featuring photophysically innocent boron cluster-based ligands (Figure 3A) [3]. Upon graduating from UCLA, Gonzalez continues to pursue her passion in materials chemistry at Brandeis University as a Ph.D. student in Prof. Grace Han's laboratory. She is currently conducting research on energy storage materials in the solid state and their applications in controlled heat release. Recently, Ali was a lead author on a review work describing solid-state photoswitching of molecules in a condensed phase [4]. Aside from conducting research, Ali enjoys working as a teaching assistant for the organic chemistry laboratory and fine-tuning her already impeccable repertoire of puns and one-liner jokes.

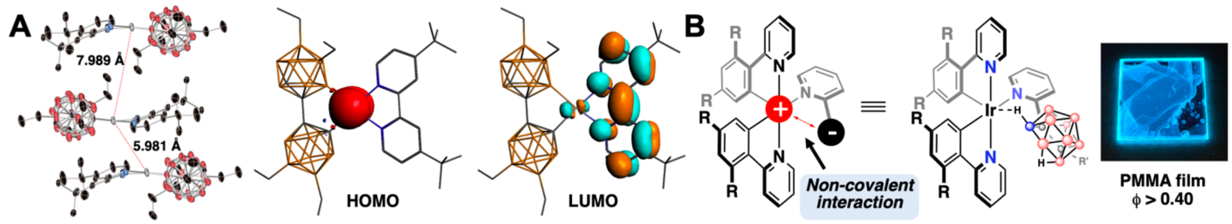

Figure 3. Development of photophysically innocent carborane-based scaffolds for metal-based phosphorescent materials. Figure 3A was partially reproduced from materials in [3] with the permission from the Royal Society of Chemistry. Figure 3B was adapted with permission from [9] Copyright (2016) American Chemical Society.

Like most other high school students in Suzhou, China, Yanwu Shao (Figure 1) spent most of his time focusing on the subjects required by national college entrance examinations: Chinese, mathematics and English. He quickly realized that his college life at UCLA would be very different. After arriving in Los Angeles in 2012, Yanwu decided to dedicate his undergraduate studies towards chemistry. Yanwu's research experience began in 2015, where he joined the Spokoyny research group and pioneered synthetic methods for the preparation of $B_{12}(OR)_{12}$ clusters (Figure 4A,B) [5]. This effort was foundational to the development of several research thrusts in the laboratory including the generation of photooxidants, hybrid polymers and atomically precise nanoclusters [6,7]. With the guidance of senior group members, Yanwu was able to master numerous synthetic and analytical skills. This training became extremely useful for his subsequent studies as a Ph.D. researcher at Texas A&M where he has been studying the synthesis and characterization of bimetallic pincer complexes. During his time at UCLA, Yanwu also learned to appreciate other fields outside of the sciences such as linguistics, sociology and film studies. He plans to blend together his multifaceted interests in his future career upon graduating from Texas A&M this year.

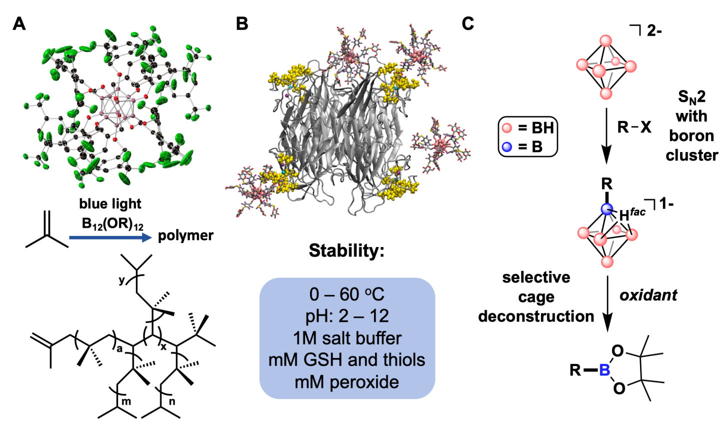

Figure 4. Recent developments in the area of polyhedral boron clusters in the Spokoyny group with contributions from the undergraduate researchers. A. Discovery of perfunctionalized $B_{12}(OR)_{12}$ cluster photooxidant and weakly-coordinating proanions for polymerization. B. Development of cluster-based platform for multivalent protein binders. C. Umpolung approach towards nucleophilic borylation chemistry using $B_6H_6^{2-}$ cluster. Figure 4A was adapted with permission from [6] Copyright (2016) American Chemical Society.

Upon starting at UCLA, Elamar Moully (Figure 1) quickly identified her passion for chemistry and biology. While classes were often difficult (she still has nightmares about her last organic chemistry exam!), laboratory courses were her favorite—three hours of mixing chemicals, setting up impressive glassware, and feeling like a “real” scientist. She decided to dive deeper into the world of chemistry research, and worked in the Spokoyny research group during her last two years. At first, as she admits, it was slightly terrifying. This was Elamar’s first time handling chemicals outside of a classroom setting, and she was constantly afraid of causing a catastrophic explosion. But with time, practice, and some guidance, Elamar found her footing. While in the group, Elamar was exposed to the marvelous world of boron cluster chemistry, and had the opportunity to initiate several thrusts pertaining to bioinorganic chemistry. One of these was her contribution to the development of atomically precise, organomimetic clusters capable of multivalent molecular recognition (Figure 4B) [7]. This work, which was published in 2016, was her first scientific contribution to the world. Additionally, Elamar pioneered some early discoveries from the group pertaining to a new bioconjugation strategy for biological molecules using organometallic boron clusters. Elamar is currently a Ph.D. student at Northwestern University working on the design of high-throughput biochemical assays for a variety of applications, such as single-cell analysis and metabolic pathway characterization. Elamar was recently a lead author on a manuscript describing her Ph.D. work generating assays to measure tyrosine phosphatase activity in single cells [8]. She plans to graduate within the next year and pursue a career in science education and outreach. She hopes to work on STEM program development, both in and out of the classroom, to inspire the next generation of scientists.

Vinh Nguyen (Figure 1) was born and raised in Southern California. During his time as an undergraduate at UCLA, he entertained various career paths through various internships, including those at St. Mary’s Medical Center, CalTeach, and UCLA CityLab. However, it was research in the Spokoyny group that ultimately sparked his current interests in synthetic chemistry. Vinh cites an enthusiastic group dynamic and opportunity to study the light-emitting and material properties of carborane complexes (Figure 3B) as a major force that encouraged him to pursue a career in research [9]. Following his graduation, Vinh was employed as an R&D analytical chemist at Catalent Pharma Solutions in San Diego, where he designed HPLC methods and supported manufacturing of Phase I/II pharmaceutical candidates. Currently, he is a chemistry Ph.D. student at Texas A&M University working in the laboratory of Prof. Oleg Ozerov. His projects revolve around developing catalysts that regioselectively functionalize pharmaceutically and agriculturally relevant compounds. In the future, Vinh plans on pursuing a research-oriented career with opportunities to pay forward his knowledge and received mentorship.

Figure 5. A cohort of undergraduate researchers in the Spokoyny laboratory who worked in the group circa 2016-2018. Top: Joshua Martin (left), Chantel Mao (center), Azin Saebi (right). Bottom: Daniel Mossalaei (left), Monica Kirollos (center), Paul Chong (right).

Joshua Martin (Josh, Figure 5) was born in Washington D.C. and grew up in Rome, Italy where his parents worked for the United Nations. He later moved to Southern California to pursue a B.S. in Biochemistry at UCLA. Josh spent nearly two years working in the Spokoyny Lab, where he focused on the palladium-catalyzed, boron-vertex functionalization of carboranes, culminating in several seminal contributions (Figure 1) [10,11]. During his time in the lab, he learned how to set up moisture and air-free reactions, analyze the results and interpret their significance. The most significant intangible skill that Josh learned during his undergraduate research experience was the importance of connecting disparate fields in a way that had previously been overlooked or underappreciated. Josh is currently a Ph.D. candidate at the University of Michigan, Ann Arbor where he works under the tutelage of Prof. John Montgomery. His work aims to develop novel methods for the construction of complex carbohydrates. Recently, Josh and co-workers reported a discovery of efficient and simple glycosylation via fluoride migration catalysis [12]. After completing his Ph.D., Josh hopes to pursue a career in the pharmaceutical industry which he hopes can be located in an area with an abundance of very spicy food, which he enjoys a lot.

After being intrigued with the prospects of what inorganic chemistry can offer while taking Spokoyny's undergraduate course, Chantel Mao (Figure 5) decided to join our laboratory and experience it firsthand. While Chantel originally wanted to get hands-on experience in the lab in order to prepare for a career in chemical industry, her plans slowly changed as she became immersed more in the world of synthetic inorganic chemistry. During her stint, Chantel learned how to conduct laboratory synthesis and contributed to the group's methodology in carborane chemistry. Research sounded intimidating to Chantel at first, but with the encouragement and support of her co-workers, she developed a solid foundation of functional knowledge. Chantel collaborated with senior group members on the development of new methodology for carborane cluster functionalization. This work culminated in a publication paper disclosing dramatically improved Pd-based cross-coupling reactions and nucleophilic aromatic substitution reactions with carboranes [13]. She is currently pursuing her Ph.D. in chemistry at UC Davis in Marie Heffern's laboratory, and is truly enjoying her time in graduate school despite being significantly farther away from Universal Studios and Disneyland. While still interested in inorganic chemistry, Chantel has been expanding her expertise and moving towards the exploration of metals in medicine and biology.

Back in high school, chemistry was Azin Saebi's (Figure 5) *least* favorite science course. There were always too many exceptions to the "rules" for her liking and electrons just didn't behave! This trend continued until she took chemistry in Saddleback Community College. Learning organic chemistry was especially fun. Upon transferring to UCLA, Azin took an inorganic chemistry course with Spokoyny and really enjoyed learning about inorganic elements and how they are used in our daily lives. In that class, Azin discovered her passion for boron clusters and shortly began her stint in the Spokoyny lab. Having had very limited experience in chemistry labs, everything was new to her: the Schlenk lines, glove boxes, rotor evaporators. Through her hard work and tireless mentorship of senior group members, things improved fast, and Azin found many amazing friends in the lab who would be support system for when her reactions didn't work as well as expected. During her first phase in the group, she collaborated with Elamar Moully, Daniel Mossalaei and colleagues to generate atomically precise organomimetic clusters [7]. She then started an independent project on development of histone deacetylase inhibitors, which would marry the two fields she was most excited about: neuroscience and chemistry. On her very last day in the laboratory, she synthesized the final target molecule, which was later shown to be biologically active [14]. Azin's experience at UCLA helped her form a better understanding of her aspirations, and shaped her current career path. Azin is now a Ph.D. student at the Massachusetts Institute of Technology working on the development of antimicrobial conjugates using palladium-mediated bioconjugation chemistry and chemical synthesis of proteins. Recently, she and her colleagues reported a significant breakthrough in chemistry showcasing an automated synthesis of large proteins [15]. After graduation, Azin is hoping to use her expertise to contribute to making new therapeutics and treatments for infectious diseases.

Daniel Mosallaei (Figure 5) grew up in Orange County suburbia and spent most of his adolescence finding adventures and getting into trouble with his friends. As he admits, he was far from a good student. After attending a local community college Daniel was able to excel academically and found his passion for chemistry. Two years later, he transferred to UCLA and was inspired by an inorganic chemistry course taught by Spokoyny. After joining the Spokoyny lab, Daniel struggled at first, but his fellow undergraduate and graduate students from the lab quickly showed him the ropes. Other than the plethora of hands-on chemistry and laboratory experience, Daniel found the weekly group meetings to be incredibly beneficial to his own learning. Daniel was ecstatic when his hard work in the laboratory paid off and he became a co-author on a publication [7]. Daniel notes that the Spokoyny group became his second family, and he made lifelong connections during his time there. Daniel graduated Summa Cum Laude with highest departmental honors from UCLA in 2016, which was a stark contrast to his original academic performance in earlier life. He decided to pursue a medical degree and began attending USC Keck School of Medicine the next Fall. He has recently finished his 3rd year in the medical school and is currently continuing to conduct research in the laboratory of Mei Chen doing bench-to-bedside research in wound healing and *epidermolysis bullosa*. Daniel plans on applying to dermatology residencies in the 2021 cycle and continuing his career in medicine.

Monica Kirollos (Figure 5) was born in Cairo Egypt, and has lived in California since moving stateside. She joined the Spokoyny lab in October of 2015, working on the synthesis of tunable and atomically precise nanoparticles from stable boron clusters. Her work in the group was tremendously enjoyable, because not only did she learn air- and moisture-free techniques, handled expensive equipment, and mastered NMR software, but she also gained a family of coworkers and a mentor whose advice remains invaluable to her until today! Being a team player paid off, as Monica and her colleagues developed and recently published a new discovery and method showcasing how one can efficiently use small boron clusters for nucleophilic borylation of small molecule electrophiles (Figure 4C) [16]. Monica's lifelong passion has been medicine and the potential to help people. She has now started her second year at the Mayo Clinic Alix School of Medicine, and has continued to pursue her growing interest in research. Monica plans to incorporate evidence-based medicine into her practice by working in an academic setting and contributing to the scientific community with innovative and meaningful research.

Having failed chemistry in high school, Paul Chong (Figure 5) believed that he was simply not cut out for the sciences. He ended up dropping out during his junior year in favor of obtaining a GED. As a nontraditional student returning to education and attending community college in his twenties, Paul was required to enroll into a general chemistry course, which seemed daunting at the time given his prior experience with the subject. However, his concerns were alleviated by a superb line up of instructors at his local community college. Upon completing the first course in organic chemistry, Paul began a search for research opportunities with no clue of where to start. He contacted about a dozen principal investigators and received a lone reply from Spokoyny who agreed to host and train him in his lab. Paul notes that his time in the Spokoyny lab turned out to be a transformative experience that finally convinced him that he belongs in the sciences. As a sophomore community college student, Paul has co-authored a manuscript from the lab disclosing the discovery of $B_{12}(OR)_{12}$ clusters as extremely strong photooxidants [6]. Paul developed immense enthusiasm for research and eventually transferred to UCLA in order to complete his undergraduate degree while continuing research on polymer chemistry [17]. Under the guidance of Paul's graduate mentor (Dr. Marco Messina), he learned essential laboratory skills that he uses to this day, but more importantly, he learned how to think critically in performing research. Paul's undergraduate research experience shaped his ultimate decision to pursue a graduate education in sciences. Over a decade after failing his first chemistry course in high school, he is now a Ph.D. candidate in chemistry at Stanford University, performing research at the interface of materials chemistry and neuroscience. Paul and his colleagues recently published a manuscript on the development of new tools for minimally invasive sono-optogenetics [18].

Alex Umanzor (Figure 6) was born and raised in Long Island, New York to Salvadoran immigrants. His mother is a nurse practitioner, so growing up surrounded by her medical encyclopedias made him fall in love with science at a young age. His passion for chemistry, similarly to many others, began in high school. Alex initially struggled in his freshman chemistry class, but once he found the study method that worked best for him, he began to excel. He took his newfound interest and ran with it, enrolling in a summer class at Columbia University called Intensive Seminars in Modern Chemistry. Conducting experiments in a research lab and attending seminars from the likes of Ged Parkin and Ronald Breslow ignited his passion for the subject. Upon starting at UCLA as an undergraduate, Alex has struggled to stay afloat in the cutthroat STEM classes. However, all of this changed when he joined the Spokoyny group. Mentored by several senior graduate students and post-docs, Alex worked as an undergraduate researcher for three formative years, focusing on boron cluster-based applications to organic synthesis [16]. Doing hands-on chemistry fueled his determination to improve his academic performance as well as dedicate time to research. His work on sterically unprotected nucleophilic boron cluster reagents later resulted in his first co-authored publication, which Alex cites as one of the greatest accomplishments of his undergraduate career. After graduating from UCLA, Alex moved Minneapolis where he is currently a first year Ph.D. student at the University of Minnesota, Twin Cities. Now that Alex is on the "other side", he is excited to pay forward the mentorship he received and mentor undergraduate students throughout his graduate career, and one day become a professor of organic chemistry at a predominantly undergraduate institution.

Figure 6. A cohort of undergraduate researchers in the Spokoyny laboratory who worked in the group circa 2017-2020. Top: Alex Umanzor (left), Kevin Qian (center), Gustavo Marin (right). Bottom: Omar Ebrahim (left), Ramya Pathuri (center), Morgan Hopp (right).

Kevin Qian (Figure 6) had a long-standing interest in chemistry, and his understanding and appreciation for the subject has grown substantially because of the mentorship he received over the last several years. Kevin began his undergraduate studies in chemistry at Columbia University in 2016. Then in the summer of 2018, he was accepted into the Amgen Scholars program at UCLA, which provided him the opportunity to work in the Spokoyny laboratory for a few months. Although it was a relatively short stint, it was very productive. Working as a part of a team, Kevin and co-workers studied reactivity of the *closo*-$B_6H_6^{2-}$ cluster as a sterically-unprotected nucleophilic boron reagent. Kevin's involvement in this project was an incredibly informative and humbling experience as it presented him with a new world of questions and challenges. Furthermore, he found that his time spent in the Spokoyny group was particularly enriching because of his exposure to their interdisciplinary approach to science. Being in the presence of researchers who were exploring a great variety of problems has helped him better understand and contextualize his work within the broader scientific community. Kevin is currently pursuing a Ph.D. in Chemistry at the Massachusetts Institute of Technology, with a long-term goal of a career in academia.

Gustavo Marin (Figure 6) was born in Queens, New York, where he lived until the age of 14. Afterwards, he moved to his family's home country of Colombia to finish high school. Gustavo always dreamed about attending UCLA for his undergraduate studies and his dream eventually became reality. Once he moved to Los Angeles, he quickly realized that he was going to be challenged personally and mentally in order to become a successful scientist. Upon joining the Spokoyny research laboratory, Gustavo learned that an entire world of intelligent people exists around him outside of classes, and that he can tap into this collective knowledge to advance his learning. Gustavo worked on several projects that explored using boron clusters as cross-linkers in the synthesis of hybrid polymers (Figure 7) [19]. Importantly, he believes that this research experience allowed him to be exposed to invaluable materials characterization techniques and tools ranging from powder X-ray diffraction analysis (PXRD) to scanning electron microscopy (SEM) which he would not have experienced by simply taking courses. Upon graduating from UCLA this year, Gustavo returned back to Colombia and is currently living with his family, eagerly anticipating the end of the COVID-19 pandemic. He is currently enjoying spending time with his family and also pursuing mini projects like trying to learn a new language (French). Ultimately Gustavo is planning to continue his research endeavors as a Ph.D. student in materials chemistry.

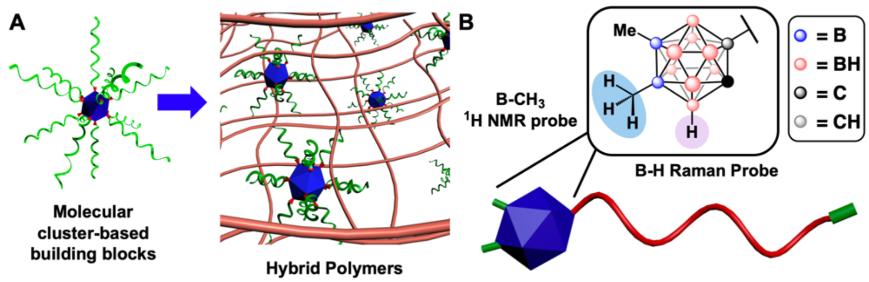

Figure 7. Recent utilization of boron-rich clusters as building blocks for polymer materials developed by UCLA undergraduates. A. Perfunctionalized boron clusters can be applied as cross-linkers for hybrid polymers. B. Carboranes can be employed as unique NMR and Raman spectroscopic handles for controlled polymerization.

Being diagnosed with diabetes as a child, Omar Ebrahim (Figure 6) did not understand the difference between insulin types, why mixing insulins creates crystals, or why glucagon pellets had to be dissolved in strong acid before administration. He originally planned to address this gap in understanding by pursuing a medical degree. But his experience working with in multiple laboratories at UCLA, allowed him to take an unconventional approach to human disease by developing synthetic chemical tools to probe or augment biomolecules. Working jointly in the Spokoyny and Maynard laboratories at UCLA, Omar was part of the team effort focused on the development of carborane containing chain transfer agents used to characterize polymeric materials grown via reverse addition fragmentation chain transfer polymerization. The carborane functions as a Raman probe, allowing us to characterize polymers in biological media [17]. These fundamental techniques have carried over into his graduate career at Northwestern University where he is now developing peptide brush polymer displays of various incretins to not only protect the peptides from degradation, but engender new therapeutic properties not present in the individual free peptides. Eventually, he hopes that these new therapies will combat unaddressed comorbidities in patients with Type 2 Diabetes. Despite mounting evidence to suggest that the pathophysiology of diabetes is more complicated than previously thought, little information is translated to patients and patient care remains stagnant.

Ramya "Maya" Pathuri (Figure 6) was born in an immigrant family and grew up in a small town in north Georgia where her love of science was greatly encouraged by her high school chemistry teacher. Though she was initially interested in a pre-medical track, once at UCLA, Pathuri found that she was much more excited by basic research. In the spring of her second year, Pathuri joined the Spokoyny research group. Pathuri's first project involved the design and implementation of carborane-based chain-transfer agents (CTAs) for radical addition-fragmentation chain-transfer (RAFT) polymerization [17]. Her work contributed towards a paper, on which she was co-author, published in *Polymer Chemistry*. Pathuri's second project involved the design, characterization, and application of anion-based room-temperature ionic liquids (RTILs) based on the tunable *closo*-$B_{12}H_{12}$ scaffold. Specifically, she developed ionic liquids that facilitate electrodeposition in high-vacuum environments, and this work was done in collaboration with the Air Force Research Laboratory (AFRL). Starting this Fall, Pathuri is pursuing a Ph.D. in chemistry at Northwestern University.

Morgan Hopp (Figure 6) learned the word "experiment" and its definition in preschool and could not wait to tell her mom that day. This passion was solidified by her amazing AP chemistry teacher who inspired Morgan to further explore chemistry. She decided to enroll at UCLA as a biochemistry major to prepare for a future career in medicine. Morgan joined the Spokoyny lab as an undergraduate researcher to explore further educational options, as she had never met someone who did chemistry research and wanted to push her boundaries. Given Morgan's interests on the interface of biology and chemistry, she embarked on a collaborative project focused on developing carborane clusters as substitutes for adamantane in pharmacophores to target epigenetic regulation. Three years later, after much contemplation and exploration, Morgan still plans to be a medical doctor, but admits that she absolutely loves chemistry research. In fact, she decided to delay her UCLA graduation and pursue an advanced master's degree to stay an extra year to do research through a department honors program. She recently co-authored a manuscript showcasing the synthesis of carborane clusters with appended N-based reactive functional groups [20]. Morgan finds it extremely rewarding to have seen a project progress from theoretical concepts sketched on a piece of paper into the development of molecules that can be implemented in animal testing. Morgan is currently in the process of applying for admissions to medical schools across the country. She strongly believes that her work in the Spokoyny lab on understanding the implications of drug design will make her ultimately a better doctor.

Improving Chemistry Appreciation Among STEM and non-STEM Students:

In addition to undergraduate mentorship, Spokoyny's long-term goal is also to improve undergraduate education in chemistry. A recent report from PCAST on STEM education [21], for example, cited "uninspiring introductory courses" as a major reason for the low attrition rate among students in sciences. The same report recommends the "diversification of teaching methods" as a solution to this problem. Young and idealistic minds would be more cognizant to learn and rationalize chemical concepts by considering their historical and societal contexts. By incorporating these concepts in the form of case studies in the structure of the introductory inorganic course Spokoyny has taught, we attempted to engage students and help them establish connections between fundamental and applied chemical sciences and contemporary societal problems in the areas of environment, energy, and healthcare. Knowledge creation has been another focal point of our attempt to revive the excitement among students in the classes. For the inorganic chemistry courses Spokoyny taught, we have implemented two assignments which were designed to engage students in a collaborative effort to produce either a Wikipedia article on a non-existent area of research pertaining to inorganic chemistry or a short documentary video for Youtube featuring a site or a person within Southern California who is deeply impacted by inorganic chemistry [22]. These assignments not only allow our students to apply their creativity that sometimes cannot be harnessed through traditional paper-based examinations, but also produce a potentially useful piece of digital and open-source information benefiting the public. Similarly, in the upper division/graduate chemistry course that was taught, we covered frontiers of the inorganic chemistry interfaced with biological systems. Importantly, during this course, students developed an original research idea and put together a formal research proposal, which was then evaluated by a student-based peer review panel (similar to a NIH study group). This assignment was extremely popular with the students (especially undergraduates) and allowed us to mentor them throughout a 10-week period in identifying a suitable research topic and proper framing of scientific arguments.

Over the past several years, Spokoyny has also revamped an inorganic synthesis laboratory course to incorporate guided and open-inquiry pedagogical strategies. The main objective of this course was to introduce students to a collaborative project in inorganic chemistry, which tackles the unknown. This is in contrast to the traditional "cookbook" laboratory chemistry courses at UCLA, which make students work on projects that have been tested and validated and the answer to the problem being solved is already known. During the first time the class was offered in 2017, students quickly picked up on the techniques and were able to complete a significant body of work developing a new class of precatalysts for metal-catalyzed cross-coupling. Importantly, course lecture meetings were held in the format of a group meeting, where we discussed ongoing progress in the laboratory and theory behind methods and strategies to tackle and troubleshoot challenges one can encounter in the laboratory. The work that was performed by this class was disclosed in a peer-refereed journal in the field [23], and every undergraduate was included as a co-author. This is important since 90% of the students in the class did not perform formal undergraduate research at UCLA, although the majority of these individuals attempted (unsuccessfully) to find a suitable laboratory and mentor. The format of this class therefore helps to address the issue of poor scalability in our department (as well as many other departments across the nation) in terms of individual undergraduate mentorship, where given the large number of students it is nearly impossible for everyone to be hosted in a single PI's research laboratory. Conceptually, this course can be thought of as a short-term undergraduate thesis project, which is a common model for independent research at liberal arts colleges. Importantly, the original success of our effort was recognized by the community and the class saw a dramatic increase in enrollment [24, 25].

Lastly, we have been working on development of a new course (Chemistry 3) at UCLA targeting non-STEM majors that covers essentials of modern chemistry and materials science. This is important, since the fundamental mission of our teaching is to educate the future electorate and enable these individuals to make well-informed decisions. While chemistry surrounds essentially every aspect of our life from vaccines to plastics, we tend to overlook explaining fundamental importance of our field to the general non-science audience. We've all heard that familiar groan, a subtle shifting of eyes when you announce your STEM class will involve a writing-based project. As educators we share the burden of addressing more than the course materials prescribed by the title of the class. We attempt to develop a multitude of facets of scientific literacy: enhanced written communication skills, an appreciation for the historical context of a discovery, ways of critically evaluating new information and so many more. This can be especially challenging considering the time restrictions of university courses.

In 2018, we developed the first general education chemistry course at UCLA (Figure 8). Previously, students from non-science majors would satisfy this requirement by enrolling in the introductory chemistry courses also taken by students in the major. While these courses represent a fundamentally important survey of the underlying concepts of basic chemistry, the highly mathematical nature of the course alienates many from appreciating the broader impacts of a chemical education. Furthermore, many non-STEM students at UCLA feel a lack of belonging in a science classroom which figuratively solidifies the physical divide between the sections of campus where non-STEM and STEM students are taught (historically refereed to at UCLA as "north campus" versus "south campus"). We observed these events and developed the class, Material World, to showcase key materials throughout history and how the properties of these materials have shaped our society. From the smelting of metals to the advent of various plastics to the generation of medicines and biological warfare, a survey of approachable topics conveys underlying principles ranging from density to nuclear fission.

The pilot course was administered in 2018 and was well-received. One point of improvement was the quarter-long project, which required students to write a mock press release of a recently published research journal article. While educational, the assignment felt antiquated with little tangible outcome. Through the assignment, we hoped students would visualize how warped information can become through media interpretation. But was there a better way to achieve this goal incorporating, perhaps, a modern and accessible platform? We taught the class again in 2019 but with a new project in mind. We envisaged how social media, primarily Twitter, could be utilized as a tool for identifying the spread of scientific misinformation. Given the restrictions of social media, students would have to be brief in articulating counterarguments, a valuable writing skill. We also saw the opportunity for both creativity and interactivity which we hoped would make researching new topics more rewarding to our students.

To achieve these learning outcomes, we allocated the mandatory discussion section time attached to the regular lectures in the course as an evolving forum for the Twitter project. The class was broken into two discussion sections, each meeting once a week. We split the sections into groups of 2-3 students and each group made a new Twitter account, specifically for the course. Each group was asked to find one false scientific claim recently posted on Twitter and to respond to it, politely, articulately and with cited sources. The students were then assigned due dates at which time they presented the transcript of the communication to their respective discussion section and explained the concepts underlying the misinformation. Because social media updates in real time, they were free to engage with Twitter whenever and wherever they chose, lending flexibility to the assignment. The platform is free and easily accessible. After tutorials on how to navigate Twitter as well as examples of effective communication, the students got started. They were graded on how thorough and well referenced each response was, how well they presented the topic and timely completion. The groups with the top three presentations were asked to present to the entire class and were awarded extra credit. This gave a chance for everyone to hear the most thorough, yet succinct responses as a template for future Twitter communication while also providing incentive for students to be fully invested in the assignment.

Figure 8. Key contributors to the development of Chemistry 3 course at UCLA: (left) Mary Waddington (teaching assistant), (center) Roshini Ramachandran (science education expert and instructor during Fall 2020) and (right) Alex Spokoyny (course originator and instructor during Fall 2017-2019).

The results of this exercise were very promising. Students who had never read a scientific journal before were analyzing article findings to present in their maximum 280-character responses. Due to the nature of social media, students were forced to be concise, organized and brief, choosing every word extremely carefully. While some original posters responded to the students with negativity upon being corrected, a significant fraction did not. We found an exchange with a medical doctor from Florida to be particularly interesting. The original tweet states "A popular workout supplement is #Creatine. Unfortunately, it may accelerate male pattern #hairloss by increasing DHT." The tweet then provided a link to an article in the *Clinical Journal of Sports Medicine*. The students read the article and realized that while correlations between DHT (dihydrotestosterone) and creatine were reported, hair loss was not included or even commented on. Further, the small sample size (n= 20) limits widespread applicability. The students provided links to other published studies as well as a popular podcast explaining that baldness is more complicated than correlation to DHT levels. Through this exercise, the students evaluated research conclusions while crafting a counter argument within the space of a couple tweets, exemplifying the goal of interfacing social media and education.

In anonymous reviews of the class, one student wrote "I've learned a lot about different materials that are highly relevant to my everyday life and critical perspectives of viewing our society!" We believe this exercise produced new tools by which our students can engage with the media and critically assess the information provided. With the recent transition we've all made towards remote learning, projects that force students to engage with one another while developing essential writing, communication and research skills are increasingly important. We implemented this project to fit a classroom setting, but the structure could easily be extended to a virtual setting, providing a free, accessible and engaging learning tool. We coined the project the "Twitter Throwdown" and hope our experience encourages more educators to employ social media as a tool for preparing students to practice scientific inquiry and make well-informed decisions in their daily lives by dissecting the real from the fake scientific news.

Importantly, we believe that these assignments help to improve a general science appreciation among the students and increase their performance towards achieving anticipated learning outcomes in the course (Figure 9). Further evaluation of this course and its impact on student's science appreciation is currently underway. Nevertheless, it is already apparent that this course is a very successful test bed for developing clear explanations and analogies necessary to make the material interesting to a broad audience of social scientists and humanists. Furthermore, during our evaluation in 2019, we observed a significant improvement in student's post-survey when asked whether learning science will affect how they vote in the elections. We are currently working on developing a laboratory module for Chemistry 3, which we believe will further improve chemistry appreciation and scientific literacy among students.

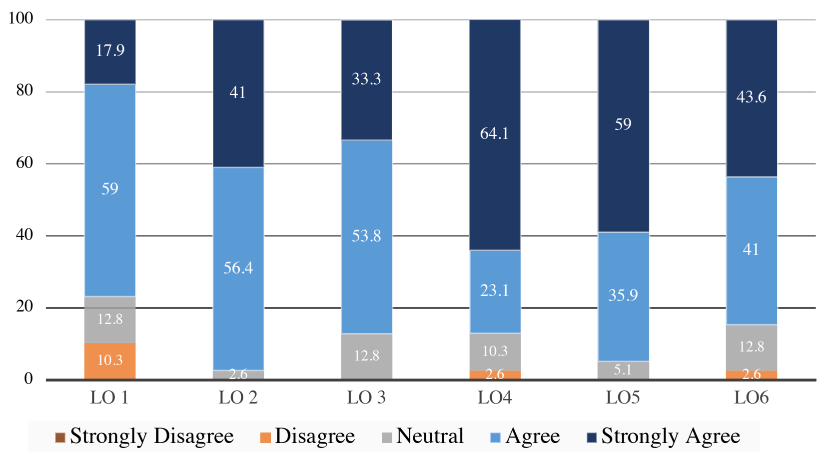

Figure 9. Summary of student post-course responses in a Chemistry 3 course taught in 2019. The question asked whether students agree that the course helped them to achieve key learning outcomes: LO1. Estimate the size and relative dimensions of the microscopic world; LO2. Explain complexities associated with the toxicity of materials; LO3. Gain a qualitative understanding of light/matter interactions; LO4. Make connections between historical and technological events; LO5. Connect technologies with societal areas of need; LO6. Predict outcomes of emerging technologies.

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