59th National Junior Sciences and Humanities Symposium

Abstracts Catalog

The abstracts in this publication are from original scientific research conducted by participating students in the 59th National Junior Science and Humanities Symposium. JSHS is a collaborative effort between the research arm of the Department of Defense Tri-Services - U.S. Army, Navy, and Air Force and nationwide academic research institutes.

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National Junior Science and Humanities Symposium

Program Objectives

- Promote research and experimentation in sciences, technology, engineering, and mathematics (STEM) at the high school level.
- Recognize the significance of research in human affairs and the importance of humane and ethical principles in the application of research results.
- Identify talented youth and their teachers, recognize their accomplishments at symposia, and encourage their continued interest and participation in STEM.
- Expand the horizons of research-oriented students by exposing them to opportunities in STEM within the Department of Defense, academia, industry, and government.
- Increase the number of adults capable of conducting research and development.

NJSHS 2021 Oral Presenters

Biomedical Sciences
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Stanley Liu
Dheepthi Mohanraj (3)
Alexa Nakanishi
Elisabeth Oskoui
Aditya Pillai
Ashwin Prabhakar
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Leonardo Zambrano Tapia
Chapin Zerner (2)

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Jillian Bernabe
Nikhita Bontha
Tianning Chen (2)
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Tahlor Johnson
Brian Lee
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Steven Liu (3)
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Varun Chandrashekhar (2)
Joseph Clary
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Nethra Krishnan
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Life Sciences
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Cheryl Quartey (1)
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Mathematics & Computer Science

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Aditya Ariyur
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Michelle Hua (1)
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Ryan Park (3)
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Boaz Yoo

Medicine & Health/Behavioral Sciences

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Emily Hood
Claire Jin
Raeed Kabir
Angelina Mao
Arjun Mazumdar
Siena Negron
Sahasra Pokkunuri (1)
Kenneth Roedl
Alexa Shaw
Allyson Sizemore
Clara Tandar
Pratik Vangal (2)
Bettina Wagner (3)
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Physical Sciences

Samad Hakani (1)
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Ashini Modi (2)
Adam Oppenheimer
Abrar Sheikh
Christine Ye (3)

NJSHS 2021 Oral Presenter Abstracts

Nereid: Using a Convolutional Neural Network (CNN) Approach, an AI Technique, to Rapidly and Accurately Detect Microbial Contamination That May Cause Water-Borne Diseases

Laalitya Acharya (2nd place, Mathematics & Computer Science)
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Teacher: Karen Young

According to WHO, 2.1 billion people lack access to clean-water, and approximately 1 out of 3 drinks from such heavily-contaminated water that they are at high-risk for severe water-borne diseases. The current-methods for microbe-detection time and cost-consuming. This proposal is a novel and interdisciplinary model using a neural network to detect microbial-presence in water. A cohesive-device was created with 3 separate systems. The first was a novel and cost-effective microscope-imaging system which utilized a microscopic lens attachment, a Raspberry Pi Zero and a Raspberry Pi camera. The second was the custom-trained neural network to analyze images of water contamination. This network was trained on 3 microbe types: Lactobacillus, Streptococcus, and Saccharomyces Cerevisiae, using TensorFlow. It used 2-features and the stochastic-gradient-descent algorithm. This training accuracy was consistently above 90%. The validation demonstrated an average accuracy of 98.53% and an F-Score of 95.70%. Lastly the transmission system used Long-Range Radio (LoRA) for communication between the “Water Pipe” and “Water Plant”. The end-to-end method is that the microscopic system takes images at regular intervals with a cron-job. These images are sent to the neural network to be analyzed for possible contamination. The network outputs the classification of the contamination, which is sent to the transmission system. If contamination is present, this system will send it to the “Water Plant” from the “Water Pipe” using the LoRA technologies. This solution is scalable and can be trained to detect multiple microbes and other contaminants and can be deployed as a commercial method of detection.

Synthesis & Characterization of Phosphorus/Nitrogen Co-Doped Carbonized Waste Cigarette Filters: Application as Textile Dye Adsorbents & Oxygen Reduction Electrocatalysts

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Mentors: Dr. Noureen Siraj and Samantha Macchi, University of Arkansas at Little Rock Chemistry Department

Two main issues within our global community are pollution and electricity access. The textile dye industry produces 7x10^5 tons of dye annually, approximately 20% of which pollute water sources. While fuel cells have potential as environmentally-friendly electricity sources, their platinum-based oxygen reduction catalysts are highly expensive and inaccessible. In this research, waste cigarette filters were explored as textile dye adsorbents and oxygen reduction electrocatalysts for fuel cells. Undoped waste cigarette filters (CF) and phosphorus/nitrogen co-doped waste cigarette filters (PNCF) were carbonized via a simple, microwave-assisted technique, using ammonium polyphosphate as the dopant. The physical characteristics (surface area, porosity, etc.) of CF and PNCF were examined. Batch adsorption experiments were performed under different conditions (initial dye concentration, temperature, etc.) to understand their adsorption capabilities for methylene blue. The potential of PNCF as an oxygen reduction electrocatalyst was examined through cyclic voltammetry in alkaline solution. Due to increased surface functionality, the maximum adsorption capacity of PNCF was 303.03 mg/g (300% higher than commercial activated carbon), compared to 212.77 mg/g for CF. A tea bag model was proposed to apply PNCF. Tea bags successfully prevented PNCF from entering solution whilst allowing 10 mg PNCF to remove >90% methylene blue. For fuel cells, PNCF exhibited a favorable oxygen reduction potential at -0.231 V and was electrochemically stable. Therefore, PNCF demonstrated the potential to serve as an inexpensive, accessible alternative to commercial activated carbon adsorbents and platinum-based catalysts, and utilizing PNCF could simultaneously help combat cigarette filter pollution.

Creation of a mechanical prothesis that together with the Arduino Mega2560 and electromyographic signals exercises basic functions of the hand at a moderate cost.

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Mentor: Dr. Pedro Albizus Campos

According to the Society for the Prevention of Vascular Diseases in Puerto Rico, about 2,500 amputations occur each year. Prices for prosthetics currently range from $20,000 to $60,000 making it hard for these people to regain their autonomy. This engineering project has the purpose of creating at a moderate cost a mechanical hand prosthesis using electromyographical signals sent to an Arduino Mega 2560 controller for it to move a stepper motor. The Arduino can read multiple signals as input and uses these values depending on the signal to move a stepper motor, this would mean that it is possible to use this mechanism. To obtain the signals I used a Myoware muscle sensor with electrodes. The Myoware sends signals to the Arduino as raw signals in which then the Arduino uses them as input values. For the prosthetic hand and fingers, I used materials from a VEX robotics kit, like metal struts for the body, aluminum bars for the fingers also some small cuts were made to make it move better and to secure the motor. The hypothesis was accepted, The controller was able to move the motors allowing the prosthetic hand to open and close with a rapid and consistent response. These results can prove the usefulness of creating a series of affordable cost prosthetics to provide users with a higher sense of autonomy.

Detection of Nm Sites using XgBoost and One-Dimensional Convolutional Neural Network

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Mentor: Dr. Doaa Hassan Salem, School of Informatics and Computing, Indiana University-Purdue University

One of the most common RNA modifications is Nm (2′-O-methylation), where the 2' hydroxyl group of the ribose sugar is methylated. Recent studies have revealed the significance of the Nm modification in multiple biological processes and diseases such as Cancer, Alzheimer's, and HIV. Because of this importance, several biochemical methods have been developed to detect Nm sites. However, these experimental approaches are expensive and time-consuming. Recently, computational approaches have provided more efficient ways to detect Nm sites. Nonetheless, there is a need for more precise and accurate computational models. The objective of this study was to address these issues by developing two machine learning models that detect Nm sites with higher precision and accuracy. Because Nm is abundant among mRNAs in the HeLa and HEK293t cell lines, mRNA was sequenced from the respective cell lines using the Oxford Nanopore Sequencing Technology: the third generation of DNA and RNA sequencing. The sequenced information was then extracted and used to compile a dataset for each cell line using the Nanopolish software package. After preprocessing, two machine learning models, XgBoost and One-Dimensional Convolutional Neural Network (Conv1D) were developed and trained with data from both cell lines to identify Nm sites in the mRNA. The XgBoost and Conv1D models both obtained high accuracies of 93% and 98% and precisions of 93% and 98% respectively, reinforcing how these models can be used to identify and predict more Nm sites, which can be vital for studying and learning about the Nm modification.

The Synthesis of Au-Fe_3O_4 Nanoparticles for the Purpose of Nonenzymatic Dopamine Sensing

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Sponsor/Teacher: Christopher Reeves

This year alone, 1 million Americans suffer from Parkinson's Disease (PD); 5 million from Alzheimer's (AD); and 400,000 from Multiple Sclerosis (MS). Neurodegenerative diseases affect the neurons of the human brain, causing neuron deterioration. Bodily functions like heart function, balance, and speech are then hampered. Recent studies demonstrate that dopamine can act as a reliable metabolic parameter for the early diagnosis of neurodegenerative disease. Therefore, the determination of dopamine concentrations in the body is of great importance.

Current methods of dopamine detection involve analytical, spectroscopic, and electrochemical techniques. However, electrochemical detection of dopamine poses as the most effective due to its sensitivity and selectivity. Dopamine detection occurs through its oxidation into polydopamine on the electrode surface, but there are various bodily substances that may interfere with the oxidation current. Hence, gold-ferric oxide nanoparticles were utilized for an increase in sensitivity, conductivity, and selectivity during dopamine detection.

In this study, Au-Fe_3O_4 nanoparticles were synthesized through a one-pot synthesis. The nanoparticles were deposited on carbon cloth substrates. The prepared electrodes were then subjected to cyclic voltammetry (CV), under a three-electrode setup to determine their dopamine-sensing capabilities. The electrodes were tested in several concentrations of dopamine starting with 5µM and ending with 200µM. Data graphs displayed that the anodic current increased substantially in the presence of dopamine, which signified the occurrence of dopamine detection. Therefore, the synthesis of Au-Fe_3O_4 nanoparticles has the potential to detect neurodegenerative disease through dopamine sensing.

Development of Novel Bipolar Membranes for Sustainable Energy Production Using H_2/O_2 Fuel Cells

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Supervising Scientist: Dr. Radhakishan Motkuri, Pacific Northwest National Laboratory

Bipolar membranes can eliminate a majority of the challenges faced by traditional proton exchange (PEM) fuel cells. Unfortunately, these membranes are weak, unstable, and inefficient, making them unsuitable for the harsh environments and significant power demands of fuel cells.

In this project, a novel concept called "Whole-Pore Bipolarity" to synthesize stable and highly efficient bipolar membranes for use in H_2/O_2 fuel cells is presented. The uniqueness of this approach is that the bipolar junction is formed as 3-D structures within the millions of pores of a Nafion™ membrane, unlike any membrane in use today. This allows the bipolar region to be orders of magnitude greater than traditional bipolar membranes. In addition, the stable Teflon backbone of the Nafion™ membrane shields the bipolar groups from the harsh acids and bases generated at fuel cell electrodes, making it suitable for use in today's working conditions.

After testing various combinations of surfactants, polymers, and modifications to the synthesis approach, the ideal bipolar membrane structure was obtained with polypyrrole incorporated into Nafion under controlled conditions of monomer concentration, contact time, and polymerization. Current-voltage data showed that the ideal bipolar membrane performance in a H_2/O_2 fuel cell exceeded that of a standard Nafion™ membrane. Finally, a previously published molecular-level interaction energy model was used to demonstrate the ideal bipolar structure with a Nafion/pyrrole composite.

The results from set a new pathway to resolving the cost and performance issues impeding H_2/O_2 fuel cells, thereby paving the way to a sustainable future using renewable energy sources.

Combatting Blindness in Under-Resourced Areas: A Machine Learning Approach to High-risk Retinal Disease Diagnosis

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Teacher: Mr. Proffitt

More than 600 million people worldwide have high-risk retinal diseases (HRD), including diabetic macular edema (DME) and choroidal neovascularization (CNV). Affected populations in under-resourced areas are almost 100 times more susceptible to blindness caused by HRD than in the United States. Therefore, an automatic diagnosis system specific to such regions is necessary. However, current research incorporating machine learning in HRD diagnosis does not consider degradations which are common in underserved areas. The goal of this study is threefold: model low-quality images through synthetic degradation, compare classification accuracies when either degradation or restoration methods are employed, and build a user-friendly algorithm that automatically delineates the retina. The open-source Kaggle OCT dataset was synthetically degraded and restored to create datasets modeling different image qualities. LeNet5, DenseNet, linear SVM, KNN, and logistic regression models were built for binary classification (DME or CNV). The DenseNet trained and tested on degraded images achieved an accuracy 40.4% higher than the average accuracy of the DenseNet trained on natural images and tested on restored images. This pattern was apparent in all five models. After alteration, DegNet (manipulated DenseNet) yielded accuracy values of 98.0% and 96.1% when trained and tested on natural and degraded datasets, respectively. Finally, a retina-delineating program (RDP) was created that accurately segmented low-quality images. Ultimately, the results establish degradation of training datasets, DegNet, and RPD as valuable tools for HRD diagnosis in under-resourced areas. Future work will focus on expanding DegNet for classification of a wider range of low-quality retinal images.

SpeakUp: A Machine Learning-Based Speech Aid to Enable Real-Time Silent Communication for the Paralyzed by Translating Neuromuscular EMG signals to Speech

Varun Chandrashekhar (2nd place, Engineering & Technology)
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Teacher: Keri Polevchak

There are upwards of 7.5 million people suffering from speech impairment caused by conditions such as stroke, ALS, and cerebral palsy. These paralyzed patients can't use the muscles in their throats to speak. However, even when a person tries to speak silently, their brain sends neurological signals to the speech system, causing muscles to generate EMG signals. Current technological solutions consist of eye/cheek trackers which are inefficient/expensive. Using modern sensors such as the Myoware these signals can be recorded. Recorded EMG signals are in a waveform and are predictable in their pattern depending on the word spoken. SpeakUp, an ML-based speech aid, uses these EMG signals and Machine Learning(ML) to help paralyzed/ALS patients communicate voicelessly, merely by articulating words without producing any sounds. SpeakUP has 3 main components: an EMG recorder, a Trained ML model, and a portal to display predicted speech. SpeakUp uses a Myoware Muscle sensor to capture EMG signals from the speech muscles. An Arduino and a radio transmitter are used to process and transmit data to a computer. A trained SVM ML model was then used by the computer to predict and display the silently spoken words on a python-based display portal built using Streamlit. SpeakUp was able to translate EMG signals into speech in real-time. Unlike other currently available speech aids, SpeakUp can be used by all paralyzed/ALS patients, irrespective of their level of disability. This device has an accuracy of 80.1% and was developed for under $100.

The Discovery of a Potential Novel Compound from Curcuma amada with Antifungal Activity on Aspergillus niger

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Teacher: Lindsey Rega

Supervising Scientist: Dr. Jie Li, University of South Carolina

Species in the Aspergillus genus (spp.) can cause severe fungal infections. Aspergillus spp. has been associated with co-infection with diseases, leading to increased complications and higher mortality. Current antifungal medications are limited and associated with serious side effects, resistance, and interaction with other drugs, indicating the need to develop a natural antifungal therapy to inhibit the growth of Aspergillus spp. and its fungal infections. Curcuma amada (C. amada) is a type of ginger plant that has been investigated for its bioactivity. Yet, its antifungal properties have been sparsely studied. The purpose of this study was to investigate C. amada's antifungal inhibitory activity on Aspergillus niger (A. niger)—a species of the genus Aspergillus— and to discover a potential novel antifungal compound from fractions of C. amada crude extract. It was hypothesized that at least one fraction would inhibit the growth of A. niger. Data from twenty-one trials and ANOVA and Tukey tests revealed that the butanone C. amada fraction significantly inhibited the growth of A. niger. This fraction was further analyzed using liquid chromatography and tandem mass spectrometry, revealing a potential novel compound of mass 339.17 m/z. The inhibition of A. niger by C. amada suggests that the potential novel antifungal compound from C. amada can be used in development of a natural antifungal medication to treat infections and co-infections caused by Aspergillus species.

Computational Design of a Multi-Target NMDAR/AChE Ligand for the Symptomatic Treatment of Alzheimer's Disease

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Teachers/Mentors: Dr. Tim Anglin and Dr. Michael Bruno, North Carolina School of Science and Mathematics

Alzheimer's Disease (AD) remains as a leading cause of death in the United States, but extensive research over the past decades have not yielded any therapies that prevent, halt, or reverse its progression. This study aims to enhance existing symptomatic therapy by designing a dual inhibitor molecule that simultaneously antagonizes both of the currently approved inhibitory targets: the N-methyl-D-aspartate receptor (NMDAR) and the acetylcholinesterase enzyme (AChE). Current NMDAR and AChE inhibitors were selected to be merged into hybrid compounds. One high affinity hybrid was then selected, based on computational pharmacodynamic and pharmacokinetic assessments, for further molecular optimization using various human Ether-à-go-go-Related Gene (hERG) blockage risk studies and pharmacophore guidelines. Of the ten resulting derivative compounds, a novel dual inhibitor was found to have a much lower risk of hERG blockage than its parent compounds, as well as high affinity for both NMDAR and AChE. Future work on designing multi-target drugs using the merged framework could lead to promising progress in mitigating the symptoms of multifactorial diseases like Alzheimer's.

On Two-Sided Matching in Infinite Markets

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Mentor: Professor Scott Duke Kominers, Harvard Business School

Matching is a branch of economic theory that has seen real-life applications in the assignment of doctors to medical residencies, students to schools, and cadets to branches of military services. Although standard matching models are finite, economic theorists often lean on infinite market models as approximations of large market behaviors. While matching in finite markets has been studied extensively, the study of infinite matching models is relatively new. Here, we lift a number of classic results for one-to-one matching markets, such as group

strategy-proofness, comparative statics, and respect for unambiguous improvements, to infinite markets via the compactness theorem of propositional logic. In addition, we show that two versions of the lattice structure of finite markets carry over to infinite markets. At the same time, we prove that other results, such as weak Pareto optimality and strong stability property, do not hold in infinite markets. These results give us a clearer sense about which matching results are the most canonical. This project was completed as a part of MIT's Research Science Institute 2020.

Modeling The Effect of Histone Methylation On Chromosomal Organization in Colon Cancer

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Mentor: Dr. Maxim Imakaev, Massachusetts Institute of Technology

Loop extrusion and compartmentalization are the two most important processes regulating the high-level organization of DNA in the cell nucleus. These processes are largely believed to be independent and competing. Chromatin consists of nucleosomes, which contain coils of DNA wrapped around histone proteins. Besides packing DNA, nucleosomes contain an "epigenetic code" - tails of histone proteins are chemically modified at certain positions to leave certain "histone marks" on the chromatin fiber. This paper explores the effect of the H3K9me3 histone modification, which typically corresponds to inactive and repressed chromatin, on genome structure. Interestingly, in H3K9me3 domains, there are much fewer topologically associating domains (TADs) than in other domains, and there is a unique compartmentalization pattern. A high-resolution polymer model simulating both loop extrusion and compartmentalization is created to explore these differences.

Development and Optimization of a 3D Clinostat to Simulate Microgravity

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Mentor: Lynn Harrison Clary, Ph.D., LSUHSC-Shreveport

Sending experiments to the International Space Station is expensive; therefore, 2D and 3D clinostats are used to perform microgravity simulations. Both machines simulate microgravity by continuously altering a specimen's orientation, but 3D clinostats rotate about two axes and simulate microgravity more effectively for cells attached to a surface. However, 3D clinostats are cost prohibitive for many research labs. To produce an inexpensive 3D clinostat, 3D printing was used to manufacture the sample holder, inner ring, outer ring and stand. The rings were rotated independently with two robotic actuators. An accelerometer was used to determine the time-averaged magnitude at different ring velocity combinations. Rotating the inner and outer rings at 0.625rpm and 0.5rpm, respectively, created a sub-optimal microgravity simulation with a magnitude of 0.033g. To further optimize operating conditions, a python program was used to model the acceleration vector. The optimal simulation had a predicted magnitude of 0.0015g when the inner and outer ring rotated at 1.5rpm and 3.875rpm, respectively. This was tested experimentally with an accelerometer, and although the vector's movement around the sphere was well dispersed, the resulting magnitude was 0.0278g. A human neuronal-like cell line was subjected to the sub-optimal and optimal microgravity simulations for 48 hours. Both simulations resulted in a significant decrease in DNA damage. This to be further studied, as it could have implications for astronauts' neuronal function on extended space missions.

Sodium benzoate induces toxicity and premature aging in *C. elegans*

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Mentor: Dr. Dong Tian, University of Colorado, Boulder

Sodium benzoate is one of the most commonly used preservatives in food, cosmetics, and medicine. Although the Food and Drug Administration recognizes the compound as safe, the effects of sodium benzoate on human health are not well studied and need to be addressed urgently. The nematode *Caenorhabditis elegans (C. elegans)* is an ideal model organism to study the health effects of sodium benzoate because it shares multiple conserved signaling pathways with mammals and has a well-established genetic toolkit. In this study, I discovered several unexpected and striking toxic effects of sodium benzoate on animal health. It causes early larval lethality at high concentrations as well as early developmental restrictions, decreased lifespan, accelerated neurodegeneration, and premature aging in a dose-dependent manner. Genetic epistasis studies determined that sodium benzoate worked in parallel with the insulin/IGF-1 signaling pathway to shorten lifespan. Mechanistically sodium benzoate induced premature age-pigments in young worms, suggesting an early onset accumulation of toxic macromolecules that contributes to toxicity and shortened lifespan. Further studies using the loss-of-function mutant of *glo-1*, encoding a key lysosome-related organelles (LRO) formation factor, revealed the age-pigments accumulated in the LRO. Using Green Fluorescent Protein (GFP) marker strains, I also uncovered the role of sodium benzoate in suppressing the *irg-1* innate immunity gene expression. The compromised innate immunity response may represent another underlying mechanism for the phenotypes described above. These results reveal the long-term detrimental effects of sodium benzoate on animal health and suggests that it may have similar consequences on human health.

Discovery of Novel Eukaryotic-like Dual Phosphatase Kinase Regulating Secretion of the Toxin Pyocyanin in P. aeruginosa

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Mentor: Dr. Sonia Bardy, University of Wisconsin-Milwaukee

The bacterium *Pseudomonas aeruginosa* causes many human and plant diseases, infecting over 50,000 people annually. ~75% of *Pseudomonas* proteins are characterized; however, pathogenic mechanisms of *Pseudomonas* infection remain unclear. To understand these mechanisms, we focused on an uncharacterized protein containing a eukaryotic-like protein kinase and phosphatase domain, referred to as the dual-phosphatase kinase 1 (Dpk1). Deletion of the dpk1 gene from the genome did not affect its normal growth, suggesting that Dpk1 provides nonessential functions. In silico modeling of the Dpk1 protein shows that it contains a bonafide eukaryotic-like protein kinase at the C-terminus and a phosphatase domain at the N-terminus. We found that overexpression of the wild-type kinase domain, but not its kinase inactive mutant, was toxic in the budding yeast. The *in vivo* data was further confirmed by an in vitro kinase assay. We also found that the Dpk1 phosphatase domain could dephosphorylate ATP, suggesting that both the kinase and phosphatase domains were functional. Interestingly, we observed a decreased secretion of the toxin pyocyanin when the dpk1 gene was deleted from the genome, whereas pyocyanin secretion was restored when complemented with the Dpk1 gene. Collectively, our data suggest that Dpk1 has a significant role in the secretion of pyocyanin.

Developing a 3D trajectory modeling system to predict the aggregation of ocean floor microplastics using neural networks

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Sponsor: Pei Zhang

The improper disposal of plastic waste has led to an abundance of plastics in the oceans, increasing at an exponential rate, and introducing a wide range of toxins and a potential global health crisis across the entire marine, and terrestrial food chain. However, the field of microplastic pollution tracking via data modeling systems are still in the early stages, and there are no accurate, high resolution, 3 dimensional trajectory modeling systems that clearly show patterns of plastic pollution distribution from the surface of the ocean, through the mid-water column, and to the ocean floor. This system was developed to simulate the 3D trajectories of individual plastic particles using a Lagrangian model, which utilizes neural networks trained with data from various prominent factors within specific regimes of ocean depths, such as experimental data, formula-derived calculations, and peer-reviewed results. Gravitational descent was modeled at each vertical depth layer, based on matrices determining the effect of various internal and external factors on plastic downward trajectories to run a sensitivity analysis on simulation models, and recurrent neural networks were used to post-process the data for later use in predictions. The sensitivity-analysis-defined range of inputs generated distribution maps highlighting regions of plastics aggregation, predominantly near gyres. After verifying the model against peer-reviewed publications, it was determined that this novel technique demonstrates a >90% probability of accurately predicting ocean-floor accumulation zones, with a p value of 10^{-4}. This system has the potential to lay the groundwork for future studies about microplastic accumulation predictions.

Endothelial Cell Derived Extracellular Vesicles as Novel Biomarkers for Acute Respiratory Distress Syndrome

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Sepsis is defined as life-threatening organ dysfunction caused by a dysregulated host response to infection. Acute respiratory distress syndrome (ARDS) is a secondary disease that may follow sepsis and is characterized by inflammation, increased vascular permeability, and endothelial cell dysfunction, and patients with severe cases of COVID-19 commonly develop ARDS. Currently, there are no approved pharmacological treatments or reliable biomarkers for ARDS. Extracellular vesicles (EVs) are membranous microvesicles secreted from the endosomal compartments or plasma membranes of cells. 22 healthy controls and 85 ICU-administered sepsis patients enrolled in this study, 21 of whom developed ARDS. Since endothelial cell damage is a hallmark of ARDS, endothelial-cell-specific EVs were isolated from the blood plasma of these patients using biotinylated CD31 and CD146 antibodies and streptavidin resin. Measurements of caspase-1, mitochondrial DNA (mtDNA), and microRNA-126 (miR-126) levels in these cells subsequently followed. We chose caspase-1 and mtDNA for their significance in pyroptosis and miR-126 for its importance in maintaining cellular homeostasis. Our data demonstrated that caspase-1 activity significantly increased in ARDS patients compared to sepsis non-ARDS patients and healthy controls, and miR-126-3p levels significantly decreased among ARDS patients, while miR-126-5p levels did not differ among the three groups. Furthermore, mtDNA levels were lower among ARDS patients compared to both non-ARDS sepsis patients and healthy controls, which constitutes a novel finding. These findings demonstrate that EC EVs could be used as a biomarker for early ARDS diagnosis and that caspase-1 and mtDNA may contribute to ARDS development as well.

The Impact of Proprioceptive Manipulation on Recovery of Walking Velocity After Amputation

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Proprioceptive neurons function as sensors of an organism's position in space and contribute largely to the control of normal motor function. It is known that the fruit fly *iav* gene mutant plays a role in the recovery of normal walking behavior after amputation, but what is not known is how the three neurons characterized by *iav* (Club, Hook, and Claw neurons) contribute to this ability. This study analyzes the Club neurons capability to recover

normal walking velocity after amputation of the right forelimb using temporary optogenetic activation and inhibition of the neuron. While amputated flies have been observed to have significantly lower velocities than non-amputated flies, it was found that when Club neurons are activated, there is a recovery of velocity to levels comparable to non-amputated flies. When the Club neuron is inhibited, it is observed that the amputated flies are unable to recover normal walking velocity, and continue to walk at significantly slower velocities than non-amputated flies. It can be concluded that the Club neurons play a positive role in the recovery of walking velocities after amputation. Future experiments must be conducted to understand the Club neurons' full role in recovery of all motor function, since velocity is only one parameter.

A Novel Approach to Citrus Disease Management: Leveraging Computer Vision, Machine Learning and Convolutional Neural Networks

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Teacher: Russel Davison

Mentor: Dr. S.K. Gupta, University of Southern California

Huanglongbing (HLB) is an incurable disease that affects citrus trees. This citrus disease is also often referred to as "citrus greening". This disease was first spotted in China in the early 1900s and was kept under control for a century. The disease started infecting plants in Florida – the largest orange-producing state in the United States – in 2005. By 2012 HLB had spread most citrus farms in the entire state of Florida and started to wreak havoc in the billion-dollar citrus industry in Florida. The disease also threatens the citrus industry in California and other states. There are microscopic, molecular, and spectroscopic techniques to detect HLB on citrus plants today, but they require a laboratory setting. These techniques are hard to implement on a large citrus grove. The only way growers could manage this disease today is by visually inspecting the plants and then removing the infected plants to control the problem. In this research project, an AI-powered method and process is defined, and an economically sustainable system is developed to identify HLB disease on the citrus plants and provide early detection signals on the citrus growers. The goal of this project is to research and develop a predictive model using Computer Vision, Artificial Intelligence, and Deep Learning using Convolutional Neural Networks to identify citrus leaves infected with the HLB disease and to implement a remotely piloted aerial system to detect the citrus leaves infected with the disease in citrus groves using the predictive AI model.

PanCan Diagnosed (a miRNA Approach): Using Feature Selection, Ensemble Algorithms, and Interpretability for the Early Diagnosis and Personalized Treatment of Pancreatic Cancer

Siya Goel
West Lafayette Jr/Sr High School
West Lafayette, Indiana

Teacher/Mentor: Brittany Croy

miRNAs have shown to be significant in the development of cancer tumors. Currently, pancreatic cancer's (PC's) early diagnostic rate is just 9% as screening methods are unattainable, making it the fourth leading cause of cancer death. Many studies have achieved low accuracy (70-75%) as they use methods that do not take into account the 33% misdiagnosis rate of PC with other cancers. As a result, feature selection, ensemble algorithms, and interpretability techniques were used to find significant miRNAs in order to construct an early diagnostic tool for PC. In the first phase, recursive feature elimination algorithms were used to find 200 differentially expressed miRNAs in PC and no PC samples as well as early and late PC samples. In the second phase, an ensemble algorithm was constructed from K-Nearest Neighbor, Naive Bayes, Neural Network, and Logistic Regression models in order to diagnose PC and distinguish between early and late stages. In the third phase, XGBoost, SHAP, and Skater interpretability methods were used to find most significant miRNAs in model predictions. In the fourth phase, a user interface, PanCan Diagnosis, was designed to test if a person had no, early, or late stage PC and also displayed

the patient's most differentially expressed miRNAs. This novel tool is the first in literature to receive a PC diagnostic accuracy of above 90%, seek miRNAs that can lead to personalized treatment of early and late stage PC samples, offers a ten-fold improvement in monetary costs, and is two times faster than current methods.

Automated Diagnosis of Glaucoma and High- and Low-Risk Glaucoma Suspect Using Deep Learning

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North Broward Preparatory School
Coconut Creek, Florida

Teacher: Howard York

Research Advisor: William Edward Hahn, PhD, Florida Atlantic University

Significance: Recent advances in computer vision have enabled accurate diagnosis of glaucoma, the leading cause of worldwide irreversible blindness, using artificial intelligence. However, few studies have successfully automated diagnosis of multiple stages of the disease's progression. The current study's convolutional neural network (CNN) distinguishes between four different clinical diagnosis categories, including normal, low-risk suspect, high-risk suspect and glaucoma with high accuracy.

Approach: 2811 color fundus images (1074 normal, 562 low-risk suspect, 149 high-risk suspect, 1026 glaucomatous) were collected from a variety of sources: Drishti-GS, RIM-ONE, Harvard Dataverse, and the Rand Eye Institute. A CNN was trained for 100 epochs, with a 80/20 split between training and validation. This study used a pretrained CNN (ResNeXt) and data augmentation on the training images. A 10-fold cross-validation was used for evaluation.

Results: The accuracy of the network trained for 100 epochs was 98.93% with a Cohen's kappa score of 0.98. The average accuracy after a 10-fold cross validation was 92.53%. The CNN achieved an accuracy of 99.76% when distinguishing between normal and glaucoma, 99.39% between normal and low-risk suspect, 99.30% between low- and high-risk suspect, and 99.57% between high-risk suspect and glaucoma.

Conclusions: While previous attempts to apply deep learning to diagnosis have found reduced accuracy for multiple classes, this model differentiated between 4 categories with near-perfect accuracy. These results demonstrate enormous potential for automated diagnosis of ophthalmologic diseases, facilitating professional medical care.

Use of Z. Matrella and F. Rubra in the Phytoremediation of Synthetic Motor Oil

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Sponsor: Mr. Karl Ackerman

Mentor: Dr. Michael Atkinson

Between 111,000 and 113,000 gallons of crude oil are used in the US daily as lubricants, which is equivalent to about 40-41 million gallons per year. A rising percentage of these lubricants are synthetics. Every day, synthetic motor lubricants that were spilled or improperly disposed of make their way into the soil, where they can have profound negative effects on entire ecosystems. This is a prevalent issue on Misawa Air Base, Japan, where not only are synthetic motor oils from cars leaching into the environment, but jet engine lubricants- such as MIL-PRF-7808- are frequently contaminating the areas around engine testing and maintenance facilities and flight lines.

Throughout many studies conducted on remediation techniques, bioremediation- more specifically phytoremediation- has emerged as a champion for its high cost-efficiency, low energy consumption, ease of implementation, and low maintenance, among other factors. The purpose of this specific study was to determine the effects of two grass species commonly found on Misawa AB on the remediation of soil contaminated with synthetic 5W-30 motor oil.

Samples of each grass species *Zoysia matrella* and *Festuca rubra* were contaminated once with one of two different amounts of the motor lubricant and then carefully cared for and observed for a 30-day period. After 30 days, each soil sample was tested and compared to an unremediated soil sample of the same oil concentration. Although some research questions remained unanswered due to inconclusive data, there was indication that *Z. matrella* was an efficient phytoremediator for both oil concentrations.

Mighty MOFs: Using Novel Catalysts to Produce Components of Recyclable Plastics

Dominic Greco
Breck School
Golden Valley, Minnesota

Mentors: Dr. Laura Gagliardi and Dr. Sam Stoneburner, University of Minnesota

The dimerization of 1-butene is a mechanism that is vital to the production of alpha-olefins, which have applications in the production of recyclable plastics, synthetic lubricants, and detergents. Current industrial methods of producing alpha-olefins involve homogeneous and zeolite transition metal catalysts, which are inefficient because they require additional processes to separate catalysts from solution and facilitate unwanted side reactions. This study investigates the effectiveness of the metal-organic framework UiO-66 in the dimerization. UiO-66 is composed of inorganic zirconium nodes each surrounded by 12 organic linkers, forming a stable and highly tunable framework. Deposition of transition metals (M^+) into the nodes creates active sites where catalysis occurs. A Cossee-Arlman reaction mechanism describes the dimerization of 1-butene on M^+/UiO-66 in the production of linear octenes and ethyl-hexene. To determine the catalytic activity and product selectivity of UiO-66 variants in the dimerization, models were created of reaction cycles using nickel and chromium as transition metals and benzoate, fluorobenzoate, and aminobenzoate as linkers. Calculations were performed using density functional theory in the Gaussian 16 program to get optimized structures and free energies for each intermediate in the dimerization process. These data suggest that a nickel catalyst with benzoate linkers is the most efficient. One reason for this could be the ability for nickel-based catalysts to have high selectivity towards linear products, a pattern called the nickel effect. This research can be applied to the production of alpha-olefins as industry will begin to shift from the current inefficient catalysts to MOFs.

Rapid, Noninvasive, Fluorescence-Based Detection for Elevated Levels of Nitric Oxide in Exhaled Breath, As a Marker for Hazardous PM 2.5 Exposure

Ambika Grover
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Mentor: Andrew Bramante

There is a clear correlation between prolonged exposure to ambient fine particulate matter (PM 2.5) and development of lethal disease. Today, there exists no personalized, quantifiable measure to gauge an individual's exposure to PM 2.5. Lung airway constriction from PM 2.5 exposure leads to elevated NO levels produced in the lungs to fight inflammation. Accordingly, excess concentration of NO (40+ ppb in adults, 25+ ppb in children) can be a viable breath biomarker for the indication of PM 2.5 -induced lung inflammation. Herein, an inexpensive, portable, rapid, and temperature-independent breath detection kit for PM 2.5 exposure was developed, based on smartphone-detection of NO-induced luminescence of DAF-2 (diaminofluorescein-2). Upon exposure to NO, DAF-2 is converted to highly luminescent DAF-2T

(exc/em 485/530nm), acting as a positive indicator for elevated breath NO levels due to PM 2.5 exposure. To begin, 8µl of 50ug/ml DAF-2 was embedded onto a filter-paper-based detection card, which was found to be stable when stored at room temperature (via repeated FTIR-analyses). A linear relationship between 60ml of 0-1000ppb NO breath concentrations and DAF-2T detector illumination was established, first via surface-luminescence spectroscopy, and later with Smartphone images, taken with 490/560nm bandpass filters, for the flash/camera, respectively. A newly created Smartphone application rapidly converts the detection card images to green-color values, with an algorithm determining the NO-breath concentration down to 10ppb. These results are time-stamped and shared, along with GPS coordinates, to build color-coded, live, and geographic PM 2.5 exposure trends, at a per-test cost of ~$5.

Application of a Deep Learning System for Scoliosis Assessment: Automatic Extraction of Skeletal Maturity Using Convolutional Neural Networks

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Atherton, California

Mentor: Dr. Bao Do, Stanford University/VA Palo Alto Health Care System

Scoliosis is a condition of abnormal spinal curvature with approximately 60,000 U.S. pediatric patients undergoing surgery or being placed into braces each year. Skeletal maturity assessment is critical for determining the treatment of pediatric scoliosis, and the most traditional method of evaluation is an independent hand x-ray. However, this x-ray leads to additional radiation and cost for patients. Other skeletal maturity classifications such as the humeral head ossification system and modified Oxford Bone Score (mOBS) can measure bone age using regions already present in scoliosis x-rays, but they have not been widely used for growth estimation due to their error-prone and time-consuming natures. In order to address this issue, I developed a machine learning system that uses convolutional neural networks to evaluate the humeral head stage and mOBS on pediatric scoliosis radiographs. After annotating 1197 de-identified scoliosis radiographs, a Faster R-CNN Inception V2 model was trained to detect the regions and an EfficientNet model was trained to classify the growth stages. Region detection had an F1 Score of 0.99. Staging classification had an overall accuracy of 89% and ICC score of 0.84. Based on published literature, this model is the first to automatically extract multiple skeletal maturity classifications from single scoliosis radiographs, yielding comprehensive data to determine indications for treatment. The machine learning system may also be used in epidemiological studies to automatically describe population distributions of skeletal maturity. This study holds promise for a reliable AI approach during surgical planning in pediatric scoliosis where reducing harmful radiation is crucial.

Observation of Kibble-Zurek Scaling Across a Classical First-Order Phase Transition

Samad Hakani (1st place, Physical Sciences)
The Gwinnett School of Mathematics, Science, and Technology
Lawrenceville, Georgia

Mentor: Professor Michael Chapman, Georgia Institute of Technology

This experiment was conducted to validate the universality of the Kibble-Zurek mechanism by applying Kibble-Zurek power law scaling in a classical first-order phase transition. The researcher hypothesized that an increase in gravity quench rate would result in an increase in the critical gravity according to a power-law scaling with an exponent of ⅔. To test the hypothesis, an initial ensemble of pendulum states in Python was evolved over time with varying quench rates. The critical point was found by searching for the point at which the mean absolute angle of the pendulum states was π/100. Three experimental groups were used, with varying initial standard deviations; four trials were conducted for each quench rate, with the average critical gravity graphed against the

quench rate for each experimental group. Single factor ANOVA tests were run on each experimental group; all three groups exhibited F values greater than F critical, indicating the null hypothesis was rejected and an appreciable relationship existed between the quench rate and critical gravity. Each log-log graph was analyzed to find the slope of the graph, which is the exponent of the power-law; all three experimental groups were within 10% of the hypothesized value, with the 1e-4 standard deviation group having a percent error of 1.74%. The analysis affirmed the hypothesis, showing that Kibble-Zurek scaling can be observed in a classical first-order phase transition. These results will allow for Kibble-Zurek based analysis models to be developed for classical first-order phase transitions whose current models are complex.

Dietary Protein:Carbohydrate Ratio Impacts Locomotion and Development of Drosophila melanogaster

Emily Hood
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The American diet, rich in carbohydrates, has been implicated in the rise of metabolic syndrome. Metabolic syndrome includes various conditions that increases a person's risk for cardiovascular disease and stroke. The model organism, *Drosophila melanogaster*, was used to determine the effect of carbohydrates on development and locomotion. The high-carbohydrate diets retarded larval growth and development as reflected by an increase in pupation and eclosion half-times and a decrease in mass at matched time points. Despite the delayed development, larvae reared on the high carbohydrate diets eventually eclosed following a rapid increase in mass during the 24-48 hours immediately preceding eclosion. Locomotion studies indicated both 1:0 and 1:6 diets impaired larval movement. Adults reared on the 1:2 diet showed a faster reaction to negative geotaxis. Small size and lack of movement result from the flies' inability to process the excess sugars. The flies' response correlates with symptoms found in both type I and type II diabetes. In conclusion, these data suggest that metabolism of dietary carbohydrate is linked to development and movement of *D. melanogaster* larvae and adults. Understanding this link could provide mechanistic insight into the relationship between carbohydrate metabolism and metabolic syndrome.

Dilated Silhouette Convolutional Neural Network: A Novel Deep Learning Framework for Human Action Recognition

Michelle Hua (1st place, Mathematics & Computer Science)
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Bloomfield Hills, Michigan

Mentor: Professor Zichun Zhong, Wayne State University

With a wide range of applications in artificial intelligence (AI), human action recognition is one of the most attractive yet challenging research fields. It has the potential to foster natural human-computer interaction, increase public safety, aid physical therapy, conduct sport analysis, etc. Human action is a spatio-temporal sequence with strong interdependencies between the spatial geometry and temporal dynamics of motion. Many AI methods have been proposed for human action recognition; however, in existing literature, there is a lack of synergy in investigating spatial geometry and temporal dynamics in a joint representation and embedding space. Therefore, I propose a novel dilated Silhouette Convolutional Neural Network (SCNN) for action recognition from a video. In SCNN, spatial geometric information of the moving human is modeled with silhouettes extracted from each frame of the video. The silhouettes are stacked along time and resampled to form a 3D point cloud, a unified spatio-temporal representation of the video action. With dilated silhouette convolutions, SCNN learns co-occurrence features from low-level geometric silhouettes and their temporal dynamics and constructs a unified convolutional embedding space, where spatial and temporal properties are integrated effectively. Geometry-based SCNN, complemented by an image-based approach, significantly improves the distinctiveness of learned features from motion. Experiment results on the public JHMDB, HMDB, and UCF101 datasets demonstrate the effectiveness of my method, outperforming all other state-of-the-art algorithms. I further integrate my SCNN model into a real-world product, an iOS app, to recognize actions and provide real-time coaching in fitness and physical therapy.

Heuristic Oncological Prognosis Evaluator (HOPE): A Novel Approach Implementing A Deep Learning Convolutional Neural Network Framework to Detect Brain Cancer, Breast Cancer, Colorectal Cancer, and Lung Cancer

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Little Rock Central High School
Little Rock, Arkansas

Teacher: Ms. Lee Conrad

Mentor: Dr. Fred Prior, Department of Biomedical Informatics, University of Arkansas for Medical Sciences

Cancer is the common name used to categorize a collection of diseases. In the United States, there are an estimated 1.8 million new cancer cases and 600,000 cancer deaths. Though it has been proven that an early diagnosis can significantly reduce the metastasis of cancer, screenings for cancers are inaccessible to a majority of the world. Machine learning approaches are increasingly successful in image-based diagnosis, disease prognosis, and risk assessment. Currently, there is no machine learning model that has an accuracy of 90% in diagnosing multiple cancers: brain cancer, breast cancer, colorectal cancer, and lung cancer. The purpose of this project was to create HOPE, the Heuristic Oncological Prognosis Evaluator, a transfer learning diagnostic tool for the screening of patients with common cancers. By applying this approach to datasets of MRI and histopathological images, HOPE 2.0 demonstrates an overall accuracy of 95.52% in classifying brain cancer, breast cancer, colorectal cancer, and lung cancer. HOPE 2.0 is a unique model, as it possesses the ability to analyze multiple types of image data: radiology and pathology images. As most algorithms possess an accuracy in the 80-90% range and focus on one specific type of image data, HOPE 2.0 is a state-of-the-art model. HOPE 2.0 may ultimately aid in accelerating the diagnosis of these cancers, resulting in improved clinical outcomes, when compared to previous research which focused on singular cancer diagnosis.

Codonify: A Recurrent-Neural-Network-based Codon Optimization Tool to Improve Protein Expression Towards Efficient Vaccine Manufacturing

Rishab Jain (1st place, Biomedical Sciences)
Westview High School
Portland, Oregon

Mentor: Aditya Kumar

Designing synthetic genes for heterologous expression is a keystone of synthetic biology. In protein sequences—as there are 61 sense codons but only 20 standard amino acids—most amino acids are encoded by more than one codon. Although such synonymous codons do not alter the encoded amino acid sequence, they are not redundant. Industry-standard codon optimization techniques based on biological indexes replace synonymous codons with the most abundant codon found in the host organism's genome. However, this technique may result in an imbalanced tRNA pool and metabolic stress which lead to cell toxicity and reduced protein expression. In this research, recurrent neural networks are used to accurately capture sequential and contextual patterns of genes. By predicting synonymous codons based on the sequential information of the host organism, protein expression can be increased while preventing translational error and plasmid toxicity. Codon Adaptation Index (CAI) was used to measure synonymous codon usage. When tested on eGFP and FALVAC-1, the model yielded a 0% mutation rate and improved CAI from 0.72 and 0.67 to 0.91 and 0.91 respectively. On a broad test dataset of 8,000 sequences, Codonify optimized CAI by 22% which correlates with an average 236% increase in expression. This research provides evidence that sequential context may yield codon selection that is more similar to the host genome, therefore increasing protein expression and the production of recombinant vaccines.

A Novel Ai-Based GPS Anti-Spoofing System with Subspace Differential Direction-Of-Arrival Estimation and Deep Learning Against Dynamic Spoofers

Milidu Jayaweera
La Cueva High School
Albuquerque, New Mexico

Sponsor: Dr. Sudharman K. Jayaweera, University of New Mexico

Many critical systems, including financial, banking, telecom and nuclear weapons, rely on the Global Positioning System (GPS) for synchronization of clocks that is essential for their operation. Malicious actors intending to disrupt these systems employ sophisticated GPS spoofing techniques that mimic legitimate GPS transmissions so closely making it difficult for even the most advanced anti-spoofing methods to detect them. This project designs a novel artificial intelligence (AI)-based GPS anti-spoofing technique that relies only on the physical attributes unique to a signal originated at an orbiting satellite. It uses a multi-element antenna array receiver to estimate the instantaneous signal direction-of-arrival (DOA) using a subspace-based statistical signal processing algorithm termed the root-MUSIC. Time-series of the estimated differential DOAs of signals are input to a convolutional neural network deep-learning classifier that learns the embedded signatures unique to the trajectories of signal sources to separate authentic and spoofed GPS signals. A software implementation of the designed system using actual GPS orbital data demonstrated over 96% accuracy even against dynamic airborne spoofers. A hardware implementation, using a 4-element antenna array, an RF-transceiver and a microprocessor, was shown to detect spoofed signals with above 93% accuracy. Unlike existing methods, this AI-based anti-spoofing system does not require knowledge of receiver's location and orientation or manual thresholds making it suitable for moving platforms. The proposed technique is capable of countering even the most advanced spoofers since it is difficult to exactly replicate the differential DOA of a satellite even by an airborne transmitter.

Using the Double Dip Transit Photometry Method to Identify Potential Habitable Planets

Makaila Jennings
Homeschool
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Sponsor: Doresa Jennings

In our quest of whether there is life outside of our solar system, the focus has been on finding planets known as Super-Earths with Earth-like qualities suitable for life, but large enough for us to see. The purpose of this study is to examine my theory that a "double-dip" in light would be spotted if a Super-Earth were following a Hot Jupiter in orbiting a star. The procedure is to setup a star planet system model in a large four-foot black box with a color changing / intensity changing LED bulb as the star and rotating on motor and suspended by string are a foam ball (Hot Jupiter) orbiting close to the star (LED bulb) and a suspended bead (Super Earth) orbiting further from the star. Data was captured with a BH1750 light meter sensor connected to an Arduino Uno. Luminosity data was measured for each light color (red, yellow, orange, blue, and white) representative of star colors at high intensity with both motors running for the orbiting Hot Jupiter and Super Earth. My conclusion is that a visible double dip from a star can be detected if a Hot Jupiter and a Super Earth were orbiting a star. The color and brightness of the star does affect the ability to see the double dip.

Functionalized Biochar for the Removal of Pesticides, Emerging Contaminants, and Heavy Metals from Water

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Lynbrook High School
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Teacher: Isaac Pallone

Mentor: Dr. Bhoopesh Mishra, University of Leeds, England and Illinois Institute of Technology

Less than one percent of the earth's water is easily accessible to us as fresh water and nearly half of this water is heavily polluted with microplastics, pesticides, and antibiotics due to waste from human establishments and agriculture. This research aimed to remove these key classes of contaminants by manipulating biochar surface area, controlling the chemical composition and catalytic properties for oxidative breakdown, adding surface complexing agents, and modifying intrinsic pore size. Six different kinds of engineered biochar were placed in water with 100µM initial pp-DDT, pp-DDE, dimetridazole, and bisphenol-A concentrations. Results show that catalyst and surface complexing agent presence coupled with high surface area are key for contaminant removal: manganese oxide and thiol functionalized milled rice husk biochar removed over 98% pp-DDT, 94% pp-DDE, 53% dimetridazole, and 95% bisphenol A were removed within 10 minutes. General trends in data demonstrate that high surface area, catalyst presence, increased pore size, thiol doping, and high carbon composition are key for contaminant sequestration. These results have the potential to revolutionize the water filtration industry by providing globally available, sustainable, and affordable means of purifying water. Integrating engineering with environmental chemistry, a filter capitalizing on biochar properties can be created for worldwide distribution at a cost of less than $1 per month and a filtration rate exceeding that of commercial filters for use in domestic, municipal, mining, industrial, agricultural, and aquatic settings.

Predicting Stress in Teens from Wearable Device Data Using Machine Learning Methods
Claire Jin, Ame Osotsi, Zita Oravecz
State College Area High School
State College, Pennsylvania

Mentor: Zita Oravecz, The Pennsylvania State University

Stress management is a pervasive issue in the modern high schooler's life. Despite many efforts to support adolescents' mental wellbeing, teenagers often fail to recognize signs of high stress and anxiety until their emotions have escalated. Being able to identify early signs of these intense emotional states and predict their onset using physiological signals collected passively in real-time could help teenagers improve their awareness of their emotional wellbeing and take a more proactive approach to managing their emotions. To evaluate the potential of this approach, we collected data from high schoolers with Empatica E4 wearable health monitors (wristband) while they were living their daily lives. The data consisted of stressful event reports and physiological markers over the course of 4 weeks. We developed a random forest model and a support vector machine model and systematically assessed their performance in terms of predicting the onset of stress events and identifying physiological signals of stress. The models showed strong performance in terms of these measures and provided insights on physiological indicators of adolescent stress.

To Dye or Not to Die: Bacterial Mutagenicity and Carcinogenesis
Tahlor Johnson
Governor French Academy
Belleville, Illinois

Sponsor: Christine Stewart

Mentor: Pamela Wamsley, Science Coach

I am researching the relationship between permanent hair dyes and their possible mutagenic properties. After reading that breast and bladder cancer were the two types of cancer most linked to hair dye and mutagenic chemicals, I performed this experiment to determine the mutagenic activity of permanent hair dyes. I hypothesized

that permanent hair dyes that contained natural ingredients would have smaller mutations on the sample bacteria. To test my hypothesis, I used an Ames Test on fives popular brands of hair dyes: Clairol Nice n' Easy, L'Oreal Paris, Garnier Nutrisse, and Revlon.

As expected, all the testing disks contained reverbants, but of all hair dyes the L'Oreal Paris hair dye had the least back mutations for both of its trials, compared to the other permanent hair dyes. The Schwarzkopf hair dye plate had the greatest number of back mutations for both of its trials, compared to the other "synthetic" hair dyes and control plates.

The expected outcome of this scientific investigation was proven to be incorrect. While the Schwarzkopf hair dye claims to contain "natural" ingredients, it was proven to be a greater mutagen than the four "synthetic" dyes. By using an Ames test, the scientist indicated that the natural hair dye could be a possible carcinogen with further testing.

Using Machine Learning to Combat Air Pollution by Forecasting Tropospheric Ozone Levels
Eliana Juarez (2nd place, Environmental Science)
V. Sue Cleveland High School
Rio Rancho, New Mexico

Mentor: Mark Petersen, Los Alamos National Laboratory

Ground-level ozone is a secondary pollutant that is harmful to urban populations by increasing risk of heart and lung disease and harming agricultural crops, and is particularly high in the developing world. To warn populations of hazardous ozone levels, I developed a code to analyze and compare different machine learning algorithms to reliably predict the ozone concentration 24 hours in advance. This project used hourly records of five weather variables and 12 air pollutant variables over the course of one year in Delhi, India to train multiple predictive models. To create the best model, this project tuned, trained, and tested seven machine learning algorithms and compared their predictive abilities using cross-validation. Among the seven models, R2 values varied from 0.39 to 0.61, with XGBoost, Random Forest, and K-Nearest Neighbors Regression ranking highest. When trained by separate seasons across five years, predictive capabilities of all models were significantly higher, with a maximum R2 of 0.75 during winter. When tested, the three best performing models could reliably predict O3 concentrations 24 hours in advance, where 50% of the predictions had a percentage error of less than 10%. These results show that weather and pollutant data have sufficient predictive power for 24-hour ozone warnings, and that machine learning can greatly improve upon simpler forecasting methods. Thus, advanced data monitoring and computing can improve safety for people worldwide.

SELD: Stacked Ensemble approach to non-invasive skin Lesion Diagnosis
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Skin cancer is one of the most common cancers in the world; melanoma alone claims more than seven lives every hour. Early detection of skin cancer is crucial in its treatment, as the estimated five-year survival rate for patients whose melanoma is detected early is ~99% but once the cancer has metastasized, the five-year survival rate plummets to below 25%. Additionally, the current gold standard has a high false-negative rate where 30% of melanomas are incorrectly diagnosed in the first medical visit. The goal of this project was to develop a non-invasive pre-screening skin lesion diagnosis pipeline. First, using transfer learning, a baseline model is developed and trained to classify a sample as cancerous or benign. Then, the cancerous samples are fed into an ensemble of models that will use a voting procedure to classify the samples among different types of skin lesions: Actinic keratoses and intraepithelial carcinoma, Bowen's disease, basal cell carcinoma, benign keratosis-like lesions, dermatofibroma, melanoma, melanocytic nevi, and vascular lesions. The ensemble of models will include several different architectures, taking advantage of the differential global and local feature extraction. This Stacked

Ensemble Lesion Diagnosis (SELD) model is trained on the HAM10000 dataset utilizing data augmentation, allowing for training on smaller datasets. SELD aims to accurately diagnose skin cancers through a non-invasive approach and contribute to the current state of medical diagnosis to ultimately improve patient health outcomes.

Analysis of the Differential Impacts of Material and Social Stressors on Mental Health during the COVID-19 Pandemic

Raeed Kabir
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Columbus, Mississippi

Mentor: Dr. Reshmaan Hussam, Harvard Business School

Depression cripples a large percentage of the population, and the novel coronavirus pandemic has acted as an additional stressor, further exacerbating a decline in mental health. To effectively combat this, more information surrounding the virus' impact on mental health is vital. The virus has introduced two substantial issues, affecting even those who have not contracted the virus: a disruption in the economy that results in large scale unemployment and loss in income, as well as laws that have limited the sociability of individuals. This project acknowledges the presence of COVID-19 and examines financial, isolative, and emotional factors as potential culprits for the rise in depression. Our project follows a "horse-race" model, where financial stressors are tested relative to limitations in sociability to see which dimension of life is more indicative of having depressive symptoms. Our results suggest the causes of depression are different for various moments in time, deeming two potential winners to the "horse-race" schematic. This study has additionally elucidated the struggles of several demographic groups during the pandemic and uncovered many underlying relationships that are especially predictive of depression, irrespective of the dimension they belong to. The data collected and conclusions made in this project are noteworthy and valuable for federal and state institutions to better allocate their resources to help the masses of people who suffer from depression in the future.

SoundScape: Real-Time 3D Sound Localization and Classification with Sensory Substitution for the Deaf and Hard of Hearing

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Thomas Jefferson High School for Science and Technology
Alexandria, Virginia

Teacher: John Zacharias

Current devices geared towards the deaf and hard of hearing, such as hearing aids, struggle to localize and transmit sounds to those with severe hearing impairments. Advanced devices, like cochlear implants, are invasive and cost $30,000 to $50,000. Devices that classify sounds, such as home alert systems, are not suited for mobile use and only recognize a limited number of noises, such as alarms and doorbells. The purpose of this project was to classify, localize, and transmit both environmental sounds and human speech to those with hearing impairments through a low-cost device worn around the user's neck. We performed sound localization with the SRP-PHAT-HSDA algorithm which uses a directivity model and the Time Difference of Arrival of incoming audio captured by a 6-microphone array. This allowed us to isolate and stream up to 4 independent audio sources to a remote server for real-time sound classification. We classified audio using an ensemble learning network utilizing stacking, where 4 deep-learning models, trained on the ESC-50 dataset, combined their outputs to produce a final prediction. The sounds were transmitted to the wearer through sensory substitution, where vibrations allowed them to feel the varying amplitudes and frequencies of sounds. Our device accurately predicted the direction (degrees) of up to 4 speakers playing simultaneously with 15.49 RMSE. The ensemble learning network also outperformed human accuracy (81.3%) by about 12%. Our results show that sound localization can be performed with a cost-efficient microphone array while classifying and transmitting audio through touch.

Soil Farms: A New Approach to Cropland Restoration

Emma Kratcha
Hankinson High School
Hankinson, North Dakota

Teacher: Patty Kratcha

The world's soils are losing their ability to naturally support crops, and many are approaching exhaustion. Erosion, soil structure degradation, nutrient loss, and soil microorganism population decline have all increased agriculture's need to extensively use chemical fertilizer. Chemical fertilizers allow for high yields, but they perpetuate and don't address the problem of soil degradation. The goal of my project was to determine if soil farms could be used to benefit cropland by increasing cropland microbiological activity, and I am proposing that farmers let their non-profiting pieces of cropland grow back into microbiologically rich prairie to be harvested and applied to unhealthy cropland. I tested how each of 5 exponentially increasing applications of prairie soil (0.25x, 0.5x, 1x, 2x, and 4x) affected the Carbon Dioxide emissions, heterotrophic bacteria populations, and actinomycete populations of three soils (sandy, silty, and clay soil). I tested each soil-application combination for CO_2 emissions for twelve hours, and I swabbed and plated soil dilutions to test for heterotrophic bacteria and actinomycete populations. I found great increases in soil Carbon Dioxide Emissions, specifically with the 1x, 2x, and 4x application rates on each of the 3 soil types. I found that the 2x application rate statistically increased the sandy and clay soils' CO_2 emissions, and the 4x application rate statistically increased actinomycete populations of each soil. In summary, soil farms show considerable potential for increasing the biological activity of soils, which could provide for better soil structures, increased capability of nutrient fixing/mobilization, and capacity to sustainably support crops.

A Novel Assay to Quantitatively Detect Bacterial Endotoxin by Harnessing PAMP-Triggered Immunity of *FRK1-LUC Arabidopsis thaliana*

Aravind Krishnan
Hillsborough High School
Hillsborough, New Jersey,

Teacher: Minh Dang

Mentor/Sponsor: Eric Lam, Rutgers School of Environment and Biological Sciences

Harvesting *Limulus polyphemus* (horseshoe crabs) to produce the Limulus amoebocyte lysate endotoxin assay for medical devices, pharmaceuticals, and drinking water is ravaging coastal ecosystems. This project develops a more sustainable and cost-effective quantitative endotoxin assay. The PAMP-Triggered Immunity response of *Arabidopsis thaliana* to pathogen-associated molecular patterns (PAMPs) was harnessed for quantitative determination of endotoxin presence based on induction of the *FRK1* gene. Transgenic *FRK1-LUC A. thaliana* were used to express luciferase (*LUC*) upon activation of *FRK1* by exposure to gram-negative bacteria. Luciferase enzyme control was first tested via plate reader, and luminescence produced by varying enzyme quantities was recorded. Next, *E. coli* ranging from $6*10^5$ to 10^3 CFU/mL were infiltrated into the leaf apoplastic space of *FRK1-LUC* and wild-type plants. Luminescence of infiltrated leaf discs was measured after adding luciferin substrate to reconstitute functional luciferase. The results showed a direct relationship between bacteria concentration and luminescence. The *FRK1-LUC* luminescence versus endotoxin concentration results yielded a formula of $y = 1518e^{0.0196x}$ ($R^2 = 0.937$). Data suggest this assay achieves a sensitivity down to 18 endotoxin units/mL ($p < 0.001$, SEM = 1.76%). To determine specificity, the SeeSAR software was used to calculate binding affinities of endotoxin (LPS) and flg22 with several receptors. Results indicate high specificity in LORE-LPS binding, signifying the luminesce results were caused by LPS concentration. This method's sensitivity and specificity combined with its elimination of environmental impacts and low cost make it a promising new bacterial endotoxin assay for pharmaceutical and drinking water testing.

LiDAR-based Environment Sensing for Visually Impaired

Nethra Krishnan
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Plano, Texas

Sponsor: Jerry Pruett

As of 2015, 217 million individuals in the world have vision impairment; it can range from low vision to deaf-blindness. Approaching the needs of the deaf-blind, it's paramount to understand that subjects don't have intact hearing as well. People who are deaf-blind are at the extreme end of the spectrum, and lead life with two impairments. The deaf-blind also includes children who are born with congenital defects (CHARGE Syndrome, Usher Syndrome, etc.). For the estimated 100,000 people in the United States who are deaf-blind, the resources devoted to aid, and accessibility are further limited. This lack of resources and aid motivated me to work on a solution that improves the lives of the entirety of the vision impairment spectrum.

A low-cost LiDAR proximity sensing system has been prototyped and tested, targeting the needs of the blind and deaf-blind. The design concept involves sensing, processing, and driving output for feedback. The LiDAR sensor was mounted on a servo to "sweep" the environment. Extensive prototype testing was performed and it was found that the LiDAR sweep provides an excellent contour of the surrounding, with no range limitation. We used a Riemann algorithm to filter out the noise observed in the data; the fundamental concept developed is to provide channels of feedback namely: audio, haptic, and tactile "directionals".

Field trials with blind subjects with various disorders were conducted in a "work-place" setting. Results from field trials with blind subjects with various disorders. Based on the subjects' qualitative feedback of the three channels of communication: the haptic feedback scored highest, followed by audible and then the tactile "directionals".

Finally, based on the field trials with the blind in a work- place setting, a six level automation augmentation paradigm was developed for the blind spectrum. These levels are a classification based on sense, execution, feedback, path finding, and hazard detection metrics - addressing all patient needs in the impairment spectrum.

Efficacy of Plant-Based Ligands on Coronaviruses

Brian Lee
Plainview-Old Bethpage JFK High School
Plainview, New York

It has been approximately 17 years since the severe acute respiratory syndrome coronavirus (SARS-CoV) epidemic and the world is presently facing the COVID-19 pandemic caused by SARS-CoV-2 virus. Both are positive sense retroviruses and currently, researchers are exploring small molecule based interventions to the different specific proteins produced by this virus. One such protein, integral to the survival of SARS-CoV-2, is 3CLpro which works as a protease to cleave the two distinct polyproteins assembled from the single RNA strand that is injected by the virus. Previous 3CLpro analyses showed that this protease was important to its metabolic processes as well, making it a viable target. Altering the active site of this protease or its important residues could change its configuration, restricting any sort of cleaving, resulting in useless polyproteins and rendering the virus mute. Additionally, SARS-CoV-2 uses an RNA pseudoknot to induce programmed RNA -1 ribosomal frameshifting in order to create two separate polyproteins. Altering the binding site between the pseudoknot structure and ribosome could result in a faulty polyprotein or the creation of only one polyprotein, deleting several important proteins required by the virus.

This project identified the active sites of both molecules, the optimal residues that are integral to the structure, and current ligands/drugs that are being manufactured and/or tested to restrict them. Using docking systems

such as AutoDock Vina, it was determined which ligands had the best compatibility with the molecule and using molecule design tools, added to their structures to better fit the target molecules.

UV-Irradiated ZnO-Coated Mesh for Efficiency Improvement in Oil-Water Separation
Charles Liu
Stillwater High School
Stillwater, Oklahoma

Teacher: James Nance

Oil-water separation with high throughput and efficiency is needed to achieve reclamation of oily wastewater. Current gravity-driven oil-water separation practices need a long time for oil to float to the surface. I worked on membrane technology for the efficient separation of water from oil. The membrane mesh was modified by ZnO using atomic layer deposition (ALD), resulting in minimal pore obstruction for water flow. Ultraviolet irradiation increased the hydrophilicity and oleophobicity of the ZnO-coated mesh, which, combined with the retention of membrane microstructure, contributed to a significant increase in water flux during oil-water separation. Permeate flux as high as 6628 L/(m^2·h) and separation efficiency greater than 99.9% were achieved in separating water from diesel. The UV-irradiated ZnO-coated mesh provides a promising approach to efficiently separate water from oily wastewater.

A Microfluidic Device for Blood Plasma Separation and Fluorescence Detection of Biomarkers Using Acoustic Microstreaming
Stanley C. Liu
Arcadia High School
Arcadia, California

Mentor: Suraiya Rasheed, University of Southern California

Human blood plasma contains biomarkers that are used for clinical diagnosis of various diseases. However, the blood of some patients is hemolyzed rapidly due to the rupture of cell membranes and releases chemicals and biological molecules that yield false-positive fluorescence detection results due to autofluorescence. The standard method for plasma separation is centrifugation, which is difficult to be integrated with downstream biomarker detection. In this project, an integrated microfluidic device for blood plasma separation and fluorescence detection of biomarkers was developed. Using the principle of bubble-induced acoustic microstreaming, whole blood controls spiked with fluorescently tagged antibodies to HIV-1 p24 protein were tested, yielding ~ 31.8% plasma yield with 99.9% plasma purity within five minutes. The separated plasma was then routed to an integrated micro-mixing chamber and mixed with HIV-1 p24 antigen conjugated beads. The bound p24 antigen-antibody complexes were captured by acoustic microstreaming and detected using a fluorescence microscope. These experiments demonstrated a detection limit of ~17 pg/µL of p24 antibody in the plasma. The microfluidic device successfully separated plasma from the whole blood control using acoustic microstreaming and integrated with acoustic micro-pumping and micro-mixing for enrichment of biomarkers by mixing p24-bound beads with fluorescently tagged antibodies. The beads with antigen-antibody complexes were efficiently captured in a separate compartment for fluorescence detection of biomarkers. Integration of multiple functionalities on this single disposable microfluidic chip can facilitate rapid detection of biomarkers and be used for monitoring patients' specimens in real time. This work was recently published in a peer-reviewed journal.

Optimizing *Nannochloropsis* Growing Conditions for Biodiesel Production Through Analysis of Lipid Content
Steven D. Liu (3rd place, Chemistry)
Shady Side Academy Senior School
Pittsburgh, Pennsylvania

Mentor: Dr. Devon Renock

Fossil fuels have propelled society to our current technology, but the future of energy lies in renewable resources, starting with vehicles. Despite constituting 5% of total vehicles in the US, medium to heavy-duty diesel trucks are responsible for 23% of annual CO_2 emissions in the transportation sector. Energy-dense algae are more suitable feedstocks for biodiesel and circumvent many of the problems posed by current biodiesel feedstocks, such as the requirement for arable land. *Nannochloropsis* is a promising genus of algae due to its high productivity and lipid content. Here I show how to optimize the growing medium composition for increased biodiesel quality while maintaining high productivity by quantifying the constituent fatty acid type and composition using gas chromatography (GC). The algae are grown in two groups of three 2.5L glass jugs spanning three concentration levels of nitrates and phosphates. The algae grown in low, medium, and high nutrient concentrations produced an average absorption rating (a measure of biomass concentration) at 750 nm of 0.91, 0.99, and 1.18 g/L, respectively, after 32 days of growth. The maximum monounsaturated fatty acid (MUFA) concentration of 62.68% of total fatty acids was reached in a low nutrient concentration, which corresponds to high-quality biodiesel. Through this study, a scientific breakthrough was achieved by maximizing both the quality of biodiesel produced, which is beyond any currently available biodiesel, and also the quantity with a productivity of greater than 100 times the current biodiesel feedstocks.

Analyzing the Effectiveness of Nutrient Placement on Crop Production and Soil Fertility: A Study of the Law of Limiting Factors: Phase V
Kayla Livesay (3rd place, Environmental Science)
Van Buren Schools
Keosauqua, Iowa

Mentor: Mike Plecker

I tested how the applications of Sulfur and Calcium impacted the soil fertility of *Zea Mays* (corn). By examining the yield as well as a soil analysis I was able to evaluate the environmental impacts. Discovering methods to increase production is a critical task of the agriculture industry moving into the future. By looking at nutrient relationships we can better understand the Law of Limiting Factors and produce a higher yielding crop. Additionally, growers can feed the world's rising population with environmentally safe practices. A better understanding of these results can help reduce the dependency of fertilizers that run off into rivers and streams, harming the environment.

Previously I grew corn indoors, then moved outdoors researching the effects of macronutrients on growth, health, and yield. This year I was striving to discover a precise, natural solution to raise yield with secondary nutrients while monitoring similar components. I concluded that the application of Sulfur and Calcium to the *Zea Mays* created a 54% increase in yield. Additionally, they retained more nutrients in the soil. This is indicative that future applications of fertilizer could decrease. Economically, this reduces inputs and improves profits. Environmentally, as more sustainable methods of agriculture are discovered soil fertility could continue to improve while protecting our habitats.

Generating Electricity from Natural Evaporation with Nanomaterials
Ariel Ma (3rd place, Engineering & Technology)
'Iolani School
Honolulu, Hawaii

Mentor: Dr. Jian Yu, University of Hawai'i

With climate change being a major source of concern, natural evaporation has recently become a contender for renewable energy due to its immense potential. Natural evaporation induces a capillary flow in a porous medium. Due to the surface charge carried by the porous medium, the capillary flow creates an ionic current, also known as the streaming current, which leads to a stable streaming potential that can be extracted as electricity. This study investigates the possibility of using polymer thin films to generate electricity from natural evaporation. The polymeric system based on polyvinylidene fluoride (PVDF) is considered due to its widespread use in a variety of applications as well as the simple fabrication procedure of such films. Porous PVDF films can be created by incorporating a variety of nanoparticles through a simple mixing procedure. I used three nanomaterials: graphene oxide, carbon nanotubes, and silica. The role of evaporation in generating electricity is confirmed by varying ambient conditions. Silica has been found to generate the highest voltage, while graphene oxide has the highest short-circuit current. Nanoparticle content in the PVDF film plays an important role; too few nanoparticles result in a lack of strong capillary flow, while an excessive number of nanoparticles will suppress the flow due to excessive water absorption beneath the surface. The device can be modeled as a simple circuit powered by a current source with strong agreement between theoretical modeling and experimental data. Results confirm that nanocomposite polymer films can generate electricity through natural evaporation.

Targeted Breast Cancer Therapy Using Nanoparticles Modified by Tumor-Homing Peptides

Angelina Mao
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Mentor: Dr. Yan Li, University of Oklahoma

Nanoparticles are promising cancer drugs but cannot target cancer cells, causing side effects in cancer therapy. Hence, my research question is whether adding a tumor-homing peptide could enhance the anticancer activity of photothermal and chemotherapeutic nanoparticles. To address this question, I developed cancer-targeting nanoparticles made of photothermal nanocrystals as nanocores and doxorubicin-loaded mesoporous silica as nanoshells. The nanoshells were functionalized with a breast tumor-homing peptide. To synthesize such nanoparticles, I first prepared the nanocrystals that could absorb a tissue-penetrating near-infrared light to generate heat. I then coated them with a layer of mesoporous silica, which was further chemically conjugated with the peptide and electrostatically loaded with doxorubicin at a high encapsulation efficiency (~90%). The nanoparticles could not only rapidly liberate heat in response to near-infrared irradiation but also selectively release doxorubicin in the tumor-like acidic environment. I verified that fluorescently labeled nanoparticles could enter breast cancer cells but not healthy breast cells by confocal microscopy. I used near-infrared light to irradiate the cells (treated by the nanoparticles or control drugs including free doxorubicin) for 5 minutes and then evaluated cell viability under different treatments. The nanoparticles, instead of the control drugs, could be specifically internalized in the breast cancer cells, killing them without destructing the healthy breast cells, through a combination of both photothermal therapy (by light-triggered heating) and chemotherapy (by releasing doxorubicin). Therefore, the introduction of a tumor-homing peptide could improve the anticancer efficacy of the new nanoparticles that hold promise as effective drugs for targeted breast cancer therapy.

Demystifying 'Fake News': Evaluating Media-Borne Misinformation through the Novel Application of AI-Powered Sentiment Analysis

Arjun Mazumdar
Bronx High School of Science,
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Mentor: Dr. David Rothschild, Microsoft Research Lab

'Fake news' is an insidious threat which is known to misinform and influence millions of voters in democratic elections, cost global markets nearly $80 billion in damages annually, and incite ethnic violence, killing hundreds. To address the emergent infodemic of media-borne misinformation, researchers have applied a series of computer

science, linguistic and political communication theories to detect ‘fake news’ articles. The primary challenge facing researchers in the ‘fake news’ detection field is the deficit of trustworthy and representative data, and rudimentary, inefficient applications of AI. This paper addresses both, where presenting an original deep learning model to detect ‘fake news’ through tone and sentiment in text. I produced a multi-nodal perceptron neural network classifier trained on a dataset of 40,000 vectorized articles hand-labeled by experts as ‘fake’ or ‘true.’ Using the General Inquirer tonal lexicon (compiled by Harvard psychologists), I predicted article falsity through sentiment analysis, testing the performance of this methodology using Naive Bayes, Logistic Regression and neural network classifiers. My sentiment analysis-neural network methodology yielded an unparalleled 94% accuracy rate, with a 0.98 AUC value. I also identified several sentiment categories which are most frequently used by ‘fake news’ authors to misinform; these include personal pronouns (you/yours), gendered language (he/her), and overstatements. Not only are these findings useful to academics working in social cognition and computer science fields, they can also be applied to explain how advertisements, falsely-promoted medical remedies, and propaganda in general influence human behavior.

The Engineering of a Biomimetic Airfoil to Improve the Acoustic Silencing and the Aerodynamic Capabilities of Micro Aerial Vehicles (MAVs) Through Ornithological Adaptations and Camber Manipulation for Military and Commercial Applications

Irelyn Meckley
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Camdenton, Missouri

Sponsor/Teacher: Christopher Reeves

Research and development surrounding aerial technologies has grown exponentially in recent years due to the diverse applications in both the military and the commercial sectors for physical security, environmental conservation, scientific research, and commercial delivery. The purpose of this study was to test novel biomimetic adaptations, specifically from the field of ornithology, for the purpose of improving the aerodynamic capabilities and developing an acoustically silent airfoil. The biomimetic airfoils in this study featured camber technology and were 3D printed in several filament types including: nylon, polylactic acid (PLA), and thermoplastic polyurethane (TPU). These filaments ranged from rigid to highly flexible in an effort to calculate the shock absorbent qualities of each filament type and the effect camber has on the overall air resistance. Using a hydrodynamic water tunnel in combination with an ultraviolet laser apparatus, the amount of cavitation produced by each 3D printed airfoil was quantified. The airfoils that featured biomimetic adaptations and camber technology were able to reduce cavitation when compared to the cavitation produced by current airfoil designs. The airfoils printed in the flexible filament also reduced the average amount of cavitation by 70% when compared to the airfoil in the rigid material. The airfoil designs, engineering process, and method of experimentation featured in this study will contribute to future novel drone designs for the purpose of improving stealth, safety, and efficiency.

Mechanical Properties of Ice Reinforced with Partially Entangled Hemp Fibers

Luke Millam
Lathrop High School
Fairbanks, Alaska

Teacher: Christopher Benshoof

Mentor: Jason Millam

Transporting heavy supplies to remote villages in Alaska such as Bettles and Tanana can only be accomplished by vehicular ice bridges. Constructing these ice bridges by artificially thickening the ice can be time consuming, and

many villages can't be reached until late winter. Climate change has decreased the natural thickness of ice in water ways and hampered construction of ice bridges. Reinforcing these ice bridges with partially entangled hemp fibers can reduce the required thickness of ice bridges. By partially entangling the hemp fibers through a process similar to felting, the hemp can be rolled into mats facilitating transportation and installation. In this study partially entangled hemp fibers were placed in 9 smaller ice beams and tested to determine their ultimate bending strength. Each beam was subjected to a 3-point bending test. The tests showed that the beams with partially entangled hemp fibers had on average higher breaking strengths than beams constructed with non-entangled hemp fibers. Additionally, a large 8"x10"x10'-0" ice beam was only reinforced with partially entangled hemp on the bottom 2" (tensile zone) of the cross-section. By just adding 4.2 pounds of hemp to the 350 lb ice beam, the beam supported over 2,100 lbs at midspan on a 9'-0" span before breaking. The forces resisted by this large test beam are similar to those induced on a full-scale ice bridge by an HS 20 truck load. The entangled fibers also separated apart when thawed showing the environmental impact would be similar to non-entangled hemp fibers.

A Self-Replicating 3D Printer

Brian A. Minnick (1st place, Engineering & Technology)
Academies of Loudoun
Leesburg, Virginia

Teacher: John Chapin

The self-replicating machine will revolutionize human industry. The goal of this project is to create the first fully 3D printed 3D printer, the first proof-of-concept of an autonomous self-replicating machine. Previous attempts to do this have only printed 73% of the machine and required laborious assembly which makes self-replication difficult. In this project, a print-in-place printer that does not require assembly has been built and 100% of components have been printed by solving the four critical problems outlined below.

A novel method was created to print low resistivity electronic parts (problem 1). This material is 98.3% less resistive than the best commercial conductive 3D printing filament and 99.7% to 50% less resistive than high-performance experimental materials while being easier to produce allowing a functional brushed DC motor to be printed for the first time.

To control the 3D printed motors without non-3D-printable microprocessors, a 3D printed motor controller was designed and built (problem 2). The device controls the speed and direction of each motor by reading a data strip (problem 3), generated by a custom Python program, which encodes a digital model in a language unique to the printer using two machine learning techniques.

The kinematic components of the printer have been designed such that no assembly is required after printing. The fully 3D printed hotend, printed from the polymer PEEK, can be annealed after printing which may allow it to print itself (problem 4).

The final, assembled machine is the first proof of concept of a self-replicating machine.

Spatial Correlation of Binary Black Holes Calculated From LIGO/Virgo Detections of Gravitational Waves

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Caddo Parish Magnet High School
Shreveport, Louisiana

Mentor: Dr. Marco Cavaglià, Missouri University of Science & Technology

LIGO/Virgo's first, second, and third observing runs (O1-O3) successfully confirmed 39 Gravitational Wave (GW) detections from Binary Black Hole mergers (BBHs). There is currently very little known about BBHs, how they form, and the conditions in which they merge. To further understand the nature of these BBHs we computed the

two-dimensional correlation function of the BBH coalescence detections. The sky distribution of BBH coalescence events was tested for correlations at different angular scales by comparing the observed correlation function to two reference functions that were obtained from mock datasets of localization error regions uniformly distributed in the sky. A significant correlation between the BBH detections was not found in O1 and O2, but a higher correlation was detected in O1, O2, and O3 data. What this implies is that BBHs may not be randomly distributed and could be preferentially clustered at certain angular distances. In the future, we will be cross correlating BBHs to other astronomical objects such as galaxies which carry information about whether BBHs trace more closely the distribution of dark matter or that of stars harbored in luminous and massive galaxies. We will also be improving upon the current mock data set to accurately represent a random catalog of gravitational wave detections and taking into account detector sensitivities, helping to produce a more accurate correlation function analysis.

BrCaVision: Predicting Breast Cancer Prognosis by Detecting Mitosis and Identifying Histological Tumor Subtypes in Whole Slide Tissue Images using Deep Learning

Dheepthi Mohanraj (3rd place, Biomedical Sciences)
North Carolina School of Science and Mathematics
Durham, North Carolina

Mentor: Gomathi Sedhumadhavan, Bank of America

Breast cancer is the leading cause of cancer deaths among women worldwide, but early detection and diagnosis can significantly improve a patient's prognosis. Conventionally, biopsy breast tissue is graded based on morphological features such as tubule formation (subtypes), nuclear pleomorphism, and mitotic count. Identifying lesion subtypes and determining mitotic count are the strongest prognostic markers. However, the manual examination of breast tissue slides is time-consuming and subject to inter- and intra-pathologist variability. Also, many developing nations lack the skilled medical professionals necessary to provide thorough and timely diagnoses. Artificial intelligence innovations in healthcare can address these issues and the repercussions of late or incorrect diagnosis. In this research, I developed BrCaVision, a state-of-the-art automated system for determining malignancies, classifying histological subtypes, and detecting mitosis in a whole slide image. Using transfer learning methods, I constructed sophisticated dual convolutional neural network models that accomplished 85% accuracy for subtype determination and a sensitivity of 0.98 for mitosis detection in a fraction of the time required for gold standard methodologies. Furthermore, I developed a web application that allows medical professionals to input a whole slide image and obtain heatmaps that mark tissue subtypes and mitotic cell locations. By deploying the application on a public web hosting service, professionals can obtain timely and accurate breast cancer diagnosis and prognosis prediction across the world. Being easily accessible and fully automated, BrCaVision serves as a step forward in the field of bioinformatics and can save lives with reliable, accurate, and efficient breast cancer detection.

qGenerator: A Novel Way to Create Qudit Quantum Error Correction Codes

Arun Moorthy
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Scottsdale, Arizona

Mentor: Lane Gunderman, University of Waterloo and the Institute for Quantum Computing

Quantum computing promises to provide algorithmic speedups for a number of tasks; however, similar to classical computing, effective error-correcting codes are needed. Current quantum computers require costly equipment to control each particle, so having fewer particles to control is ideal. Although traditional quantum computers are built using qubits (2-level systems), qudits (more than 2-levels) are appealing since they can have an equivalent computational space using fewer particles, meaning fewer particles need to be controlled. Currently, qudit

quantum error-correction codes are available for different level qudit systems; however, these codes have sometimes overly specific constraints. When building a qudit system, it is important for researchers to have access to many codes to satisfy their requirements. My project addresses two methods to increase the number of quantum error correcting codes available to researchers. The first method is generating new codes for a given set of parameters. The second method is generating new error-correction codes by using existing codes as a starting point to generate codes for another level (i.e. a 5-level system code on a 2-level system). So, this project builds a website that researchers can use to generate new error-correction codes or codes based on existing codes.

Multi-Component Fixation Tracking in Gaze Interaction for Rapid, Non-Invasive Diagnosis of Specific Learning Disorders

Alexa Nakanishi
Greenwich High School
Greenwich, Connecticut

Mentor: Andrew Bramante

Specific learning disorders affect 15-20% of the population worldwide. However, with no universally effective method of diagnosis, diagnosis can be a slow and unsure process. This research devised a pc-based diagnosis tool for those with reading disorders, such as dyslexia, through fixation tracking in gaze interaction, using an eye tracker. Participants were asked to read three passages, while the tracker recorded their eye movements, and determined fixation numbers, durations, and progressions. The resulting data highlights measurable differences between typical and atypical readers. Atypical readers averaged 1.73 fixations/sec, while typical students averaged 2.17 fixations/second. Atypical readers exhibited an average fixation duration of 2.42sec, far more than typical readers (1.17sec). Tracking of fixation location was used to monitor the reader's eye movement, so that a best-fit regression and R^2 correlation could be determined for each line of text within the passage. Typical students' eye movement was linear across each line of text, with an R^2 correlation of >0.35. Eye movement of atypical readers, conversely, was irregular across the same text (R^2 of ~0.083). Fixation, duration, and linearity data were analyzed against each student's reported medical diagnosis to derive selection criteria for atypical readers; fixations/sec <1.95, fixation duration >1.55 sec, and eye-movement R^2 correlation of <0.35. Blind prediction of each participant's medical diagnosis, using these selection criteria, yielded accuracies of 91%, 94%, and 100%, respectively, highlighting the efficacy of this simple, rapid pc-based diagnostic tool. Finally, measure of these selection criteria for new patients highlights a 100% accuracy for typical versus atypical readers.

Political Bias Assessment

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SkyView Academy
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Teacher: Lori Twehues

The "Political Bias Assessment" study aims to answer the question, "Does an individual's inherent political bias toward the source of their news and self-identified party affect their perception of the information provided?" Subjects first took a pre-survey reporting their political party affiliation, opinions about the accuracy of Covid-19 testing, efficiency of Covid-19 restrictions, and their preferred trusted news source. They then watched two news clips about the accuracy of Covid-19 testing. One video clip was from Fox News, however both the logo and news banner were replaced by a CNN logo and news banner. The other video clip was from CNN, however, both the logo and news banner were replaced by a Fox News logo and news banner. Subjects took a post viewing survey and reported which news source they trusted more and their reactions to the different videos. The data revealed a statistically significant association between a self-identified party and the news logo trusted by the viewer. The chi-square statistic is 8.9091. The p-value is .002838. The result is significant at $p < .05$. Apart from one individual out of thirty-four participants, no one questioned the validity of the content provided from the news clips. This

study could be used as a future application to help people be aware of their biases, think for themselves, and avoid outside factors influencing their decisions and actions.

An Investigation of Blazar Jet Variability through an Analysis of Ton 599

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Teacher: Melissa Shandroff

Mentors:Reshmi Mukherjee, Barnard College
Qi Feng, Ari Brill, Columbia University

Blazar jets are known for their dramatic variability in photon flux, seen through flares within their jets. The physics behind these flares is unknown; by analyzing variability within a blazar jet and determining the timescales on which such variability occurs, more knowledge about emission mechanisms within blazars can be learned. The goal for this project was to determine and model the flaring periods within a light curve for the blazar Ton 599 to determine limits on the variability time for the source. The light curve was partitioned using Bayesian blocks, a method which creates a step function associated with a time signal, allowing for selection of flares within the light curve. The Bayesian blocks were used in conjunction with the quiescent flux to determine the time periods of the flares. Finely binned light curves were made for these time periods, which were then modeled with an exponential profile. The parameters from these flare models were able to provide an upper limit on the size of the emitting region for the Ton 599 blazar jet of 6.6×10^{-3} light years. Additionally, the flares observed were all shown to be fast rise, exponential decay type flares, which can be explained through the lens of instantaneous particle injection into the jet or through geometric effects of viewing the jet from an angle.

Molecular Docking Analysis of Resiniferatoxin Interactions with TRPV1-6

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The Potomac School
McLean, Virginia

Mentors: Katherine Huffer, PhD Candidate, Johns Hopkins University and National Institutes of Health
Sonya Hanson, Research Scientist, Flatiron Institute

Transient receptor potential vanilloid (TRPV) channels are expressed in many cell types and some detect noxious thermal and chemical stimuli. Due to TRPV1's role in pain perception, the study of TRPV ligands is highly relevant to the development of treatments for chronic pain. Although transient receptor potential vanilloid 1 (TRPV1) is the only TRPV channel activated by vanilloids, its hydrophobic binding pocket is relatively well conserved in TRPV1-6, and vanilloid sensitivity can be genetically engineered into TRPV2 and TRPV3. This study investigated how differences in vanilloid binding pocket structure impact binding of the vanilloid resiniferatoxin (RTx) via molecular docking to 16 TRPV channel structures. Analysis of RTx binding affinity, polar contacts, placement, orientation, and nearby residues making up the binding pocket provided evidence suggesting that vanilloid sensitivity could be engineered into TRPV5 and TRPV6, including which residues could be mutated to enable RTx binding. Although additional testing is needed to clearly determine the significance of the identified residues' role in vanilloid binding and activation, this new information on similarities between the binding pockets and potential mechanisms of RTx activation for TRPV channels is useful for future studies involving ligand interactions with TRP channels.

V_{BIND}: Deep Geometric Transformers for SARS-CoV-2 Treatment Design

Ryan Park (3rd place, Mathematics & Computer Science)
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Millburn, New Jersey

Teacher: Dr. Susan Arrigoni

This research presents a novel machine-learning approach for the identification of potential treatments against SARS-CoV-2, the causative pathogen of COVID-19. Despite the existence of effective vaccines, there is no widely accepted COVID-19 drug therapy. The proposed algorithm, called V_{BIND}, designs drug therapies in the form of artificial miniproteins that bind to the viral spike protein, thereby disabling SARS-CoV-2's attack method and preventing infection. A completely *in-silico* pipeline, V_{BIND} is the first fully AI-based method for the rapid development and prototyping of these COVID-19 miniprotein drugs. V_{BIND} consists of two parts: a novel deep neural network (named Geometric Transformer), inspired by advances from natural language processing, and an associated optimization module, used to design candidate miniproteins. Because it employs innovative techniques proposed herein (i.e., Manifold Attention), V_{BIND} designs potential COVID-19 drugs effectively and efficiently. Not only do V_{BIND}-created proteins bind potently to SARS-CoV-2, V_{BIND} designs them 10,000x faster than traditional approaches. This speedup allows for a significantly larger candidate drug pool, accelerating COVID-19 treatment development. V_{BIND} also operates *de novo*, meaning it is not constrained to proteins that already exist in nature. It therefore taps into the potential of trillions of unexplored proteins, some of which could contain the key to treating COVID-19. Crucially, V_{BIND} is universal: without any retraining, it is applicable to treatment design for any protein spike virus (e.g. HIV, influenza, and COVID-19 variants). V_{BIND} thus represents a powerful and versatile deep-learning tool in combating viral infection, potentially saving lives.

Developing Hydropower in Native Fishponds

Joshua Parker
Kamehameha Schools Kapālama
Honolulu, Hawai'i

Teachers: Grant Yamashita and Ali Seyedali

Loko I'a, or Hawaiian fishponds, were developed over a thousand years ago by Native Hawaiians. *Loko I'a* are masterpieces of indigenous innovation, capable of producing upwards of 2 million pounds of fish per year. However, only 28 of the original 488 exist today. Influenced by a confluence of humanism and colonialism, *loko i'a* were deemed primitive and suppressed for years. The tidal currents that pass through these fishponds can be harnessed and converted into electricity using a hydropower generator, offering a renewable energy source for nearby communities that lack access to electricity. The first aim of this project was to construct a hydropower generator capable of converting tidal energy in a *loko i'a* into electricity. Prototype 2 generated an average of 41.2 watts of energy, the most of the three constructed prototypes. The second aim was to automatically collect data for extended periods of time. An analytical software was written to collect and graph hydropower generator data. During the three-hour trial, the analytical software graphed tidal shift, flow rate, and hydropower generator efficiency data in real time. The third aim was to construct Prototype 4 with multiple hydropower generators to produce more electricity. During the two-hour collection period, Prototype 4 produced 57-87 watts. These hydropower generators are environmentally safe, do not rely on fossil fuels, and would be a welcomed addition to the community-based fishpond.

Temporal Analysis of COVID-19 Drug Repurposing in Global Medical Literature

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Mentor: Dr. David Fajgenbaum, Cytokine Storm Treatment Laboratory, Penn Medicine

The spread of the SARS-CoV-2 novel coronavirus has led to a global pandemic resulting in over 2.8 million deaths as of March 2021, and the number is increasing. Currently with vaccine distribution in progress, urgent therapeutics are needed to combat COVID-19 symptoms and aid in treatment for critical patients. This project analyzed treatment data of COVID-19 patients through published medical literature reported from global medical institutions in order to determine promising drug treatments and prioritize clinical trials. As of January 24th, 2021, 35,645 published medical literature reporting COVID-19 data from the PubMed search engine were exported to a drug registry database and 29,353 published literature were extracted for this analysis. Treatment administration numbers by drug type and efficacy rate of each treatment reported was analyzed from February 2020 to January 2021. A Pearson's r Correlation test was also performed to determine if treatment administration numbers had correlation to respective efficacy rates. The results showed Hydroxychloroquine had the most administrations with 75,328 therapeutics. Lopinavir/ritonavir and Heparin were the most successful drugs, with 70.93% and 70.32% efficacy rates, respectively. The Pearson's r Coefficient was -0.14, indicating that increases in administration rates may correlate to decreases in efficacy rates. The data shows clinical trials prioritizing Lopinavir/ritonavir and Heparin would be beneficial, in addition to increased research in other drugs and treatment methods. This initiative is urgent to combat the COVID-19 pandemic and shows the need for increased global collaboration through big data and efficient execution of drug repurposing for future pandemics.

V-Rehab: Novel Rehabilitation Method for Joint-Related Hand Injuries

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Mentor: Mohammad H. Rahman, Ph.D., University of Wisconsin-Milwaukee

Finger and joint injuries are common among children. This may come from a strain, fracture, or just overuse of the different joints. These types of injuries may occur in the three joints of the hand: the metacarpophalangeal joint (MCP), interphalangeal joint (PIP), or the distal interphalangeal joint (DIP). The key treatment for these types of injuries usually involves long term rehabilitation. However, a child with these injuries often finds conventional rehabilitation methods boring and uninteresting, which may affect the speed of the rehabilitation process. In this project, the Unity game development engine is used to design a game for children with these types of joint injuries to boost the process of rehabilitation. An Oculus Rift is used as the VR headset, and a Leap Motion Controller is used to measure the hand movements and angles of the patient throughout the experiment. A child may find the game more interesting than the normal set of exercises and, therefore, may be keener on winning the game, which will speed up the rehabilitation process. The method has experimented with ten healthy adult volunteers, and all the data are stored to establish a benchmark for healthy or recovered patients.

A Novel Alzheimer's Disease Therapeutic Model: Attenuating Hyperphosphorylated Tau and Amyloid β (Aβ) Aggregates by Characterizing Antioxidative, Anti-Inflammatory, and Neuroprotective Properties of Natural Extracts

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Teacher: Adele Cockrill

Mentor: Sateesh Pokkunuri

A recent line of drug failures to cure or manage Alzheimer’s prompted research towards discovering ways to delay the progression of this disease. Oxidative damage and neuro-inflammation were the key pathways implicated in the

pathogenesis of Alzheimer's disease. In this study, 30 natural extracts from plant roots and leaves with extensive anti-inflammatory and anti-oxidative properties were consumed by *Drosophila melanogaster*. In this plant extract medium, GAL4-UAS system was used to produce flies overexpressing $A\beta_{42}$ human transgene in all the neurons from two transgenic Drosophila lines. Using Kaplan-Meier lifespan plots, 12 extracts that increased Drosophila's lifespan the most were mixed in specific ratios to make 5 different combinational extracts. Several assays were performed to evaluate the efficacy of these combinational extracts on delaying the progression of AD. $A\beta_{42}$-overexpressing flies fed regular cornmeal were used as a control group, whereas $A\beta_{42}$-overexpressing flies fed the extract medium were used as the experimental group. In the climbing assays, 90% of 3-week-old control group flies showed decreased motor activity. However, in the experimental group only 20% of 6-week-old flies showed decreased motor activity. In the lifespan assays, Kaplan-Meier plots revealed that the control group experienced a sharp decline in survival after 2 weeks; however, the experimental group showed a gradual decline after 5 weeks. Performance index from olfactory training to evaluate the associative memory also indicated improved learning ability in the experimental group. The results of this research confirmed the hypothesis that natural extracts can be used in delaying progression of Alzheimer's and promise a lead source of pharmacologically active compounds.

Personalized Implantable Scaffolds for Wound Healing
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Madison, Alabma

Teacher: Jessye Gaines

Wound treatment and management are major healthcare problems affecting more than 7 million people in the United States and costing more than $50 billion annually. Traditional wound dressings such as gauze and bandages are not suitable for deep cavity wounds. Although skin grafting, cellular therapy, and most recently bioprinting have advanced the treatment options for deep cavity wounds these therapies are expensive, require trained personnel, and therefore are limited in their use. Most importantly, there is currently no system that can allow customization for personalized morphological fitting of the deep cavity wounds. The goal of this project was to develop an integrated system to generate personalized wound scaffolds for treatment and management. A photogrammetry based methodology was developed to acquire 3D images of deep cavity wounds. The 3D images were post processed using CAD modeling software to generate 3D printed replicas of the wounds. Multiple biocompatible hydrogels were optimized to create 3D scaffolds with a personalized fit to the wounds and tested with success. The scaffolds were further integrated with electrical and optical based components to demonstrate non-invasive monitoring of drug release and the local environment of the wound. Finally, the scaffolds were integrated with vascular cells and stem cells demonstrating high viability. The developed personalized scaffolds for treating wounds have great potential to significantly reduce healthcare costs and patient treatment time.

Cyclo.Plas: Upcycling Fish Scale Waste as an Environmentally-Friendly Thin Plastic-like Material to Combat White Pollution
Jacqueline Prawira (1st place, Environmental Science)
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Teacher: Nicole Gary

Sponsor: Aily Salikin

The five billion single-use plastic bags discarded every year are the biggest source of thin-film accumulations, or white pollution, in the ocean. Using the structure of the collagenous matrix in fish scale waste, the goal is developing materials in replacing single-use thin plastics with comparable tensile strength to plastics and degradability in soil and water with no ecotoxicity.

Fish scale waste was selected from 3 freshwater species. Development stages include fish scale pretreatment, extraction, drying/cooling, thermal dehydration (TD), and protein analysis using Bradford assay and electrophoresis. Application tests include Tensile Strength (TS), shrinkage, and transparency. Environmental tests were phytotoxicity and degradation in hydroponics and soil.

Collagenous-matrix quality is determined by pretreatment and extraction temperatures. Drying/cooling stabilizes and accelerates formation while TD enhances TS up to 68%. Protein analysis showed that higher temperatures yield higher protein content, but not necessarily higher TS. No phytotoxicity, with 100% plant survival rate and plant growth ranged from 92%-108%. Degraded under 5 weeks in hydroponics and soil. Linear dimensional shrinkage had higher performance at 130-150℃. Transparency was 74% (translucent) at RT. Critical parameters for successful formation and prototypes were developed.

The data supported that the collagenous matrix is the main determinant of TS, as the intact collagen fibrils provide the most cross-linkages and structure. TD positively influences thermal bridge formation and extended structure reformation. At optimal extraction and dehydration temperatures, TS is comparable to LDPE and meets Terrestrial Plant test. Fish scale waste is successfully 93% upcycled as thin plastic-like materials to combat white pollution.

Keywords: Fish scale, collagen, collagenous matrix, collagen fibrils, protein, structure, thin film, biomimicry, thermal dehydration, tensile strength, biodegradation, phytotoxicity

Kinect Analysis of Obstacles & Feedback for the Visually-Impaired

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Teachers: Jennifer Berry and Tommy Nguyen

Mentor: Gayathri Srinivasa

The combination of machine learning and assistive technology for the visually-impaired is challenging for numerous reasons: unaffordability, unwearability, and computational inefficiency. We present an efficient system that classifies obstacles and communicates relative proximity. We used a Kinect sensor to receive depth data (mm) and classify objects because the sensor is affordable and has considerable potential. To reduce time complexity, we used the LightGBM algorithm to make predictions from raw depths rather than expending computational power through CNNs, which necessitate image data. In the frame's obscured patches, we identified depth disparities and used optimized smoothing to calculate discrepant values relative to available data. Thus, the filtered point cloud does not throttle LightGBM with outliers. To acquire data quickly, we divided the depth frame into seven sections, enabling us to collect 7x the data. The model trained on five categories: No Obstacle, Known Obstacle, Upstairs, Downstairs, and Wall. The model's theoretical accuracy was 81.2%, and its empirical accuracy was 96.2%. We tested the device's performance by assessing statistical significance between trials run while using the device, a white cane, and a white cane with the device. Using the device with a cane resulted in a p-value of 0.044,<0.05, rendering it the statistically fastest method. Our hypothesis stated utilizing Konnect would significantly facilitate the user's traversal through tested environments, and the resultant tests confirm it. The device can be used for affordable visual therapy, replacing technologies such as electronic canes, and furthering intelligent assistive technology research.

Bioinformatic Analysis Predicts Novel Tissue-Specific Enrichment of Nucleoporin Gene Regulators

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Recent research has demonstrated that the nuclear pore complex (NPC) plays a role in gene expression and mutation of the NPC can lead to an array of tissue-specific diseases. The nature of these diseases can be attributed to the observation that the composition of the NPC is specific to the tissue it is located in. Understanding the differences of the NPC from tissue-to-tissue and the factors that control those differences are an important starting place for further NPC disease research. This study seeks to find the ways the NPC is regulated at gene-level through the development of a novel bioinformatic approach designed to characterize tissue-specific expression patterns of the ~30 nuclear pore proteins (NUPs) and predict enriched regulators of NPC gene expression in specific tissues. Data was collected from multiple online databases including the GTEx project for human NUP tissue expression data, the GeneHancer database for NUP regulatory data, and the Gene Ontology Consortium Database for organ/tissue-specific gene enrichment data. This study predicts 15 possible NUP co-regulation pairs by NPC subcomplex, 36 novel regulators of the NPC, and a total of 11 novel regulators of the NPC specific to the brain, heart, liver, and kidney. This research represents the first bioinformatic exploration focused on predicting enriched tissue-specific regulators of the NPC, and is critical for further tissue-specific disease research.

Comparison of Nickel Chelator to Current Triple Antibiotic Therapy to Treat *Helicobacter pylori* Infection

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Research Mentor: William Hansen , Iowa Wesleyan University

Helicobacter pylori is a gram-negative bacterium responsible for multiple gastrointestinal diseases, including gastritis, peptic ulcer, gastric carcinoma and lymphoma. About 2/3 of the world population is currently infected with this bacterium, with higher prevalence in the developing world. Current standard therapy utilizes two antibiotics (clarithromycin and amoxicillin) and a proton-pump inhibitor. In the last ten years, H. pylori resistance to clarithromycin increased from 9.9% to 28%. Rising antibiotic resistance and noncompliance due to side-effects result in a 20% failure rate of current regimens and raise the need for alternative treatment strategies. This study compared the efficacy of nickel chelator (targeting H. pylori's urease enzyme acid-defense mechanism) to current standard therapy. Six samples were prepared with gastric juice, H. pylori, nickel, urea and each of the interventions (clarithromycin & amoxicillin [control], clarithromycin, amoxicillin, chelator, chelator & clarithromycin, chelator & amoxicillin). These samples were set aside for 90 minutes (simulating gastric emptying time) and plated on Columbia blood agars. The CFU counts were recorded after incubating the samples in microaerophilic conditions for 2-3 days. The experiment was repeated multiple times to ensure internal reliability of results. A one-way analysis of variance was performed to compare the means of the different interventions. The amoxicillin and chelator combination showed most significant inhibition (p-value < 0.0001) when compared to the control. Chelator individually also showed significantly higher inhibition (p-value < 0.0001) than amoxicillin and clarithromycin individually. Further experimentation with an in-vivo mice model showed amoxicillin and chelator combination to be safe and have inhibitory potential.

A Brain Computer Interface System for the Improvement of Cognitive and Communication Abilities for Patients with Neuromuscular Disorders

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Teacher: Elizabeth Carson

More than 16 million people in the United States are living with cognitive impairment. Reports suggest that 12,000-15,000 people have amyotrophic lateral sclerosis. These types of debilitating disorders often make it difficult to think and communicate. The engineering goals are (i) to design an experimental study to analyze and improve cognitive performance and (ii) to develop a communication aid to support people with neuromuscular disorders using a non-invasive Brain-Computer Interface.

A low cost Emotiv EPOC+ device is used to record EEG data, which is streamed using a Python interface. The P300 event related potential embedded within the EEG signals is a response to a target stimulus event and is used to analyze cognitive abilities. After preprocessing, the features extracted from target/non-target signals are used to train a Linear Discriminant Analysis classifier. Measuring through an alphanumeric speller paradigm, the cognitive performances of the participants were in the 76%- 81% range initially but improved with the implementation of feedback sessions to 84%-89.3% range. The proposed feedback training design is an excellent way to improve cognitive abilities such as attention and speed.

Using a display matrix system with words, a software application is developed as a communication aid for neuromuscular disorder patients. This application will enable the user to communicate words by using only brain activity through P300 signals. The communication aid system was able to predict more than 91% of the words of participants' choice correctly. The final system is not only effective, but also affordable and easy to use.

"I Don't See Color": An Analysis of Racial Diversity within Prime Time Television

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Mentor: Daniel Coapstick

Racial representation on television has been changing ever since television was invented. This study aims to do three things: 1.) Track the trends television has been setting since the 1960s and showcase what the future of television might look like; 2.) Identify the audience's opinions on the growing diversification within television as well as what racial groups believe about the past, present, and future of diversity on television; 3.) Understand the impact that diversity (or the lack of) on television has had on viewers based on their perception on past shows as well as their self confidence after watching television. Using the research of Riva Tukachinsky and Dana Mastro, this project aimed to dive more deeply into the presence of people of color on TV since the start of television and less on their portrayal. The study looks to answer two questions: "Is diversity within primetime television becoming more mainstream?" and "What are primetime television viewers opinions on diversity within primetime television?" This is done by creating an examination for television shows on primetime television (ABC, NBC, and CBS). The research will potentially serve as a blueprint for further studies to look into race portrayal and the future of racial representation on television which could be extended out to other countries and point out differences in television representation.

Omnidetector: Universal Screening Test for Cancer, Stroke from Atrial Fibrillation, and COVID Thrombophilia

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Germantown, Tennessee

Teacher: Abigail Simone

Mentor: Dr. Sandeep Rajan, University of Tennessee Health Science Center

Screening strategies for Cancer and Cardiovascular Disease, US top killers, exist, but are invasive, cumbersome, and expensive. However, Circulating Tumor Cell Clusters (CTCC), seen during early stages of Cancer, and Microthrombi, precursors of multiple Cardiovascular Diseases, are larger than normal blood cells. Discrimination of such differential size by real-time ultrasound scanning of a blood vessel offers an attractive unified screening tool for Cancer, Stroke from Atrial Fibrillation, and COVID-19 related Thrombophilia.

Yeast colonies were grown to different sizes mimicking CTCC, Microthrombi, and normal blood, using sugar & starch to incubate and sodium fluoride to arrest growth after specified times. They were circulated using syringes and an infusion pump through a wall-less ultrasound phantom, made using agar (mimicking human soft tissue), and Doppler Ultrasound was performed, with screenshots taken. Key characteristics of particles of interest were identified. Ultrasound data was processed and used to train a Convolutional Neural Network. 18 models with binary classification were tested.

Doppler signals of CTCC and Large Microthrombi surrogates could be visually distinguished from normal cells, and normal saline, proving principle of ultrasound size discrimination of CTCC and Microthrombi. The most accurate model machine learning model yielded 98.35% accuracy in prediction of CTCC, exceeding human evaluation accuracy. Thus, machine learning can automate and improve detection of these maladies.

Intronic RNA as a Therapeutic Target in Neurodegeneration: A Multipronged Study of RNA Lariat Debranching Enzyme DBR1

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Mentor: Dr. Steven Boeynaems, Gitler Laboratory, Department of Genetics, Stanford University

Neurodegeneration afflicts around 9 million and costs $800 billion per year in the US. Amyotrophic lateral sclerosis (ALS) is a devastating neurodegenerative disorder and its main driver is RNA binding protein TDP-43 aggregation. TDP-43 pathology is also observed in patients with 2 types of dementia (Frontotemporal Dementia & a subset of Alzheimer's Disease). As the incidence of these conditions increase with the global aging population, there is a dire urgency in elucidating the mechanisms of TDP-43 pathology and devising novel therapeutic approaches to target it. When pre-mRNA is spliced into its mature transcript, the splicing machinery cuts out the intron, resulting in the formation of an intronic lariat that is rapidly degraded by the DBR1 enzyme. Loss of DBR1 activity prevents the degradation of lariat RNA leading to its accumulation in the cell. TDP-43 toxicity has been suggested to be ameliorated by DBR1 gene deletion. However, the underlying mechanisms remain unresolved. Here, I show that intronic RNA lariats alter the properties and toxicity of TDP-43 aggregates. Moreover, I find that lariat RNA accumulation confers general protection against proteotoxic stress events. Unfortunately, a complete loss of DBR1 has adverse effects, as its enzymatic role is essential, but the role of lariat RNA can be assumed synthetically. By exposing these to aggregate-prone neurons, synthetic lariats can work to modify proteotoxic stress and rescue neurodegenerative aggregate toxicity. Lariat accumulation is a conserved mechanism that can be used to therapeutically target stress-related aggregation in neurodegeneration.

Enzyme-responsive Procoagulant Activity by Synthetic Platelets to Treat Bleeding

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Teacher: Dr. Crystal Miller

Mentors: Ujjal Didar Singh Sekhon, Anirban Sen Gupta, and Kelsey Swingle

Platelets are responsible for promoting clot formation at a bleeding injury site by: (1) adhesion and aggregation to initiate the clot, (2) coagulation amplification by exposing phosphatidylserine (PS) on the outside of the platelet

membrane, and (3) secretion of hemostasis-augmenting molecules from platelet's cytoplasmic granules. Therefore, platelet transfusions are routinely used to treat bleeding complications. However, platelet transfusions present significant challenges such as high cost, high infection rate, limited availability and portability, short shelf life, and a need for blood type matching. An alternative strategy is to engineer synthetic platelet particles using nanotechnology that can enable functional mimicry of the platelet mechanisms. Previous research has shown that such synthetic platelet particles can mimic the adhesion and aggregation functions similar to natural platelets when liposomes are surface-modified with peptides. Here, we have built on this with new synthetic platelet designs that also mimic the coagulations amplification function of natural platelets as the liposomal membrane is enriched with PS protected by a plasmin-cleavable polymer mask. Thrombin and fibrin generation assays and microscopy and rotational thromboelastometry (ROTEM) based functional assays were used to evaluate the synthetic particles' ability to mimic the coagulation amplification mechanism of natural platelets. The synthetic platelet particles were able to improve clot formation time, thrombin generation levels, clot firmness, and resist rapid clot lysis. Results demonstrate promise for these artificial platelet systems to be used as a substitute for natural platelet transfusions in the future for the treatment of hemostatic complications.

A Short Bout of Exercise with an Immersive Virtual Reality Game Reduces Stress and Anxiety in Adolescents: A Pilot Randomized Controlled Trial

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Teachers: Angelo Piccirillo and Valerie Holmes

Mentor: Dr. Anat Lubetzky, New York University

Exercise is known to reduce symptoms of anxiety and stress; however, many adolescents lack the time or motivation during the school year to exercise regularly, particularly during more stressful times such as examination periods. Virtual Reality (VR) has the potential to make exercise more engaging than exercise alone prompting adolescent participation. This study investigated the effects of a 10-minute exercise session, with and without a VR scene, on self-reported stress, anxiety and cognitive performance in adolescents during exam times. Participants randomly assigned to a VR group (n=16) were immersed in a virtual dodgeball environment, or a control group (n=14) which played a simple game of one-on-one catch. Executive functioning was measured using the Trail Making Test (TMT) Parts A & B. Anxiety and stress were self-reported on the Pediatric Anxiety Short Form 8a (PASF) and the Psychological Stress Experiences-Short Form 8a (PSES) respectively. A mixed model repeated measures ANOVA with 1 within factor (time, 2 levels) and 1 between factor (group, 2 levels) showed that both groups significantly improved their TMT A & B performance. The VR group showed greater improvement on the TMT B than the control group, and reduced stress and anxiety scores with effect size ranging from 0.59 to 1.2 (main effect of time $P<0.001$ for all outcomes). There were no significant differences between groups and no time by group interaction for any outcome. VR has the potential to encourage adolescents to exercise promoting good physical and psychological health in the immediate term.

Simulating Direct Loading of a Vacuum Gauge's Magnetic Trap with Cold Atoms

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Mentor: Dr. Stephen Eckel, Thermodynamic Metrology Group, National Institute of Standards and Technology

We have designed and simulated a cold-atom vacuum gauge intended to trap ^{7}Li atoms using an Ioffe-Pritchard magnetic trap. It works by measuring the cold atom loss rate due to collisions between the cold ^{7}Li atoms and the

room temperature residual molecules (mostly H_2). The three trap-related quantities calculated are the capture velocity, the temperature of the trapped atoms, and the loss rate due to lasers driving transitions to untrapped states. The capture velocity determines the maximum loading rate. The temperature calculation ensures that random heating does not cause appreciable loss. The calculated capture velocity of 79.2 m/s should result in a loading rate of ~1.33×10^5 atoms/s. Further, the trap temperature is 7.00 mK, and the computed temperatures of the trapped atoms are 0.426, 0.380, and 0.204 mK along the x, y, and z axes, respectively. This indicates that random heating is minimal. However, the calculation of the transition-driven loss rate yields contradictory results: a high equilibrium population of 0.89 for the nominal ground state but a high loss rate from that state of 15900 s^{-1}. If correct, this loss rate combined with the loading rate implies an equilibrium population of ~10 atoms, too small for operation of a vacuum gauge. Thus, further simulations are necessary in order to determine and minimize the true loss rate. The most obvious alternative models the motion of atoms in the center of the trap to determine loss rates and would require ~510 hours on a standard machine: a more efficient simulation must be developed.

The Accuracy of Eyewitness Testimony

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Mentor: Jillian Eastman

Eyewitness testimony has been used throughout history, as irrefutable evidence to cases. Even though science has proven our memories are malleable, easily manipulated by words and can be contaminated by memory implantation. In this experiment, human subjects were distracted while a video of a crime was played in the background. When the video was complete, the subjects were given a paper where they had to mark what they could remember about the criminal on the video. Four testing groups were created for the experiment. The testing variable was the time points in which the experimental groups were asked to complete the criminal identification survey. The experiment not only tested the memory of the participants, but how long the memory could be stored. Those participants who were interviewed right away seemed to accurately recall the gross details but the criminal was wrongfully identified. While those who waited more than 5 days to be interviewed had a hard time identifying any traits of the criminal or details from the video. All groups struggled to identify minor details of the criminal, and some did not even know a video was even being played. Future work should be conducted on the biases of certain races or genders and how these biases affect eyewitness testimony.

Dietary Flavonoid Dihydromyricetin (DHM) Ameliorates Alcohol-Induced Intestinal Microbiome Changes Associated with Alcoholic Liver Disease

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Teacher: Siu Kong Sit

Mentors: Dr. Joshua Silva and Dr. Daryl Davies, University of Southern California (School of Pharmacy)

Chronic alcohol consumption contributes to systemic, multi-organ injury. In addition to multi-organ injury, chronic alcohol abuse has been found to shift microbiome populations in the small intestines. Dihydromyricetin (DHM), a natural flavonoid extracted from *Ampelopsis grossedentata*, significantly reduces alcoholic liver disease (ALD) outcomes following chronic alcohol (ethanol/EtOH) abuse. However, many questions remain about DHM's multi-targeted therapeutic responses for the prevention of ALD. We hypothesized that DHM would conserve beneficial bacterial population changes after chronic ethanol consumption. This project investigated the efficacy of DHM in modifying gut microbiota populations in comparison to ethanol-fed mice. We conducted a forced drinking alcohol study using C57BL/6J mice alongside daily DHM administration (5 and 10 mg/kg; intraperitoneal (i.p.)). Following ethanol studies, mice were euthanized, and 16S rRNA sequencing was performed on intestinal tissues.

Statistical analysis using GraphPad PRISM 8 was conducted to analyze the effect of DHM on microbiome populations and diversity using a 2-way ANOVA followed by a Bonferroni's test. We found that ethanol modified bacterial phyla, family, and diversity in the gut, resulting in increased populations associated with inflammation. DHM-treated mice showed similar gut microbiota distribution to the control, suggesting a reversal of the ethanol-mediated changes in microbiome shifts. Therefore, DHM modified the microbiome populations and diversity, meanwhile preventing ALD in mice models, suggesting that DHM can be utilized for multiple targets that reduce the onset of ALD. These findings collectively indicate that DHM can provide protection against ALD and other potential disorders resulting from gut dysbiosis.

Synergy Screen of NIH Oncological Drug Set VII in Combination with Aurora Kinase B Inhibitor to Enhance Chemotherapeutic Sensitivity in Small Cell Lung Cancer

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Mentor: Trudy Oliver, Huntsman Cancer Institute

Small cell lung cancer (SCLC), though comprising only 15% of lung cancers, is highly aggressive. Despite available platinum-based agents, resistance develops rapidly, accounting for a 2-year survival rate of 6% in patients. Overexpression of the MYC family of proto-oncogenes is one of the major molecular footprints in the variant subtype and more resistant SCLC. Strategies inhibiting Aurora Kinase B (AURKB), a key enzyme in mitosis and meiosis, have been shown to create vulnerability in SCLC mouse models. To explore the therapeutic potential of this strategy, the synergistic effects of Barasertib, an AURKB inhibitor, was tested in combination with 96 approved drugs from the NIH Oncological Drug Set VII individually to illuminate possible drug combinations exhibiting synergistic cytotoxicity. An *in vitro* primary drug screen was performed to identify the most efficacious drug combination using a CTG cell viability assay. Results from the cell viability study and linear synergy score were used to select 12 drugs for extensive secondary screen investigation. ZIP (Zero Interaction Potency), Bliss Independence, and HSA (Highest Single Agent) synergy models elucidate the most promising synergistic cytotoxicity combinations of Everolimus, Temsirolimus, and AZD8055 in combination with Barasertib among all variant SCLC cell lines. Interestingly, all three agents are inhibitors of mTOR (mammalian target of rapamycin), a key protein kinase that regulates proliferation and protein synthesis, suggesting a novel approach in SCLC drug therapy. This study is the first to suggest a synergistic effect between mTOR and AURKB inhibitors to heighten chemotherapeutic sensitivity in the variant subtype of SCLC.

A Biologically-inspired, Biomarker-driven, Rapid Early Warning System for Epileptic Onset Prediction and Seizure Detection using Machine Learning

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Teacher: Korin Riske

Mentor: Srikanth T. Srinivasan, Intel Corporation

Epilepsy is a chronic brain disorder impacting >65 million people globally. Each year, >100000 patients die from Sudden Unexpected Death in Epilepsy (SUDEP), many from fatal falls. A reliable seizure forecasting, and early warning system can help patients stay safe. This work presents real-time algorithmic methods for automated seizure classification by performing rapid feature extraction using CHB-MIT's scalp electroencephalogram (EEG) epilepsy database. A new time-frequency domain Discrete Wavelet Transform method toenables near 100% seizure

detection accuracy. Predicting seizures before they occur is a challenging research problem! By analyzing over 200 hours of chronic epileptic physiological data, three unique biomarker pre-seizure patterns were identified and utilized to develop a novel machine learning epilepsy prediction framework. In 16 of 23 patients, EEG data analysis shows distinct bursts of high-frequency oscillations (60-100 Hz range) preceding a seizure. A second biomarker was identified by examining fluctuations in electrocardiogram (ECG) data, called heart rate variability. Stress can precipitate seizures. By periodically monitoring variations in Cortisol, the stress hormone in the human body - elevated cortisol levels can be correlated to seizure onsets. The predictive feature vectors extracted from all three biomarkers are used to train supervised machine learning (ML) classifiers. The final trained ML model can successfully predict seizures 1-22 minutes prior to clinical onset with 91% classification accuracy. All three proposed biomarkers allow for non-invasive patient monitoring. A low-cost (<US$10), open-source electronics platform running the optimised algorithms shows promise for a wearable “epilepsy alert device” for timely patient intervention to help save lives worldwide.

Levels of Cognitive Processing in Relation to Reaction Times to External Stimuli
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Teacher: Daniel Coapstick

Sensory Processing Sensitivity (SPS) is estimated to be unknowingly possessed by fifteen percent of the world’s population, having only been researched in the past twenty years. Awareness of this innate personality trait in the Highly Sensitive Person (HSP) population has been found to be life-changing and empowering in managing all aspects of well-being, but knowledge regarding the trait is limited and further study would prove beneficial to those who are and are not highly sensitive alike. The aim of this study was to investigate a potential correlation between reaction times to external stimuli and levels of cognitive processing. Through the creation of the Wagner SPS Survey, based on the frameworks provided by Dr. Aron and Aron and psychotherapist Julie Bjelland, distinctly highly sensitive individuals were identified in a Department of Defense (DoD) American high school in Germany. Individuals whose scores fell within the predetermined threshold were selected as participants of the study. Choice-reaction time testing was then performed through a constructed Raspberry Pi apparatus. Knowing that HSPs are inherently deeper processors than the general population, a statistical analysis was performed in order to determine a correlation between the two variables. The results of the study validate the claim that there exists a correlation between levels of cognitive processing and reaction times to external stimuli, with deeper cognitive processing positively correlated with slower reaction times. As SPS becomes increasingly recognized in society, it becomes more important to understand the HSP holistically.

HemaVision: A Novel Mobile Screening System for Rapid, Inexpensive, and Automated Diagnosis of Hematological Diseases Using Deep Learning and Computer Vision
Ella Wang
BASIS Chandler
Chandler, Arizona

Teacher: Joseph Bostaph

Hematological or blood diseases afflict over 2 billion people annually and disproportionately impact developing regions where mortality rates reach 50-90%. Current disease screening methods require medical experts to manually examine blood smears using laboratory-grade microscopes, a tedious process where lack of trained personnel and appropriate equipment, particularly in resource-limited settings, hinders early diagnosis which is crucial to prevent complications and lower mortality. This project develops a novel end-to-end framework for automated hematological disease screening. A portable 3D-printed mobile phone attachment was first designed to convert a mobile camera into a microscope with 400x magnification and used to capture microscopic blood smear images for <$8. These images were normalized and enhanced using a generative adversarial network to match the quality and resolution of laboratory-grade microscopes. Blood cells in the blood smear were then segmented,

extracted, and morphologically characterized via image processing and watershed algorithms. A custom database of 10,500 blood cell images was created and used to train a second deep learning network to detect cell abnormalities and identify corresponding diseases with 98.75% accuracy. These methods were deployed in HemaVision, a web application for automated disease screening with comprehensive blood smear analyses. The system was blindly tested using 104 blood smears and achieved 98% accuracy and AUC = 0.998. HemaVision is significantly cheaper, faster, and more accessible than current diagnosis methods, enabling point-of-care applications without manual intervention. HemaVision can ensure life-saving early disease diagnostics in medical centers and remote settings where laboratory services are scarce but mobile phone infrastructure is available.

Predicting Disease-Causing miRNAs through Inferring Network Influence for in silico miRNA Drug Target Discovery

Kevin Wang
Roxbury Latin School
West Roxbury, Massachusetts

Sponsor: Ming Piao

Deadly diseases, like cancer and heart disease, are complex conditions with elusive cures, and they consistently form the leading cause of death in the USA every year. MiRNAs have been shown to play a powerful regulatory role in the progression of these diseases and have the potential to form novel drug targets. Current experimental methods, like differential expression analysis, can discover disease-associated miRNAs through time-consuming and expensive labor, yet many of these miRNAs do not make good drug targets because they play no functional role in disease progression. Methods to discover disease-causing miRNAs, involving interventional experiments in cell-line or animal models, are even more costly. We propose a novel computational method to predict disease-causing miRNAs by inferring biological characteristics of disease-causality of disease-associated miRNAs including network influence and gene conservation. MiRNAs that are highly influential in their network are likely to cause signaling cascades, core mechanisms of disease-progression, and conserved miRNAs are generally involved in key biological functions that cause disease when disrupted. We create a consensus-based approach to infer the regulatory network in disease-context miRNA expression data and then infer miRNA influence with influence diffusion. We implemented the method in three diseases: acute lymphoblastic leukemia (89% recall, 0.840 Area Under the Precision-Recall Curve), breast cancer (98% recall, 0.734 AUPRC), and Alzheimer's disease (91% recall, 0.750 AUPRC). Our method efficiently and flexibly guides the search for disease-causing miRNAs for the further elucidation of the disease mechanism and for the potential identification of novel and efficacious drug targets.

Running Form Detection Using Artificial Neural Networks and Inertial Measurement Units

Michelle Wang
Carbondale Community High School
Carbondale, Illinois

Sponsor: Stacie Massie

Of the 60 million runners in the U.S., it is estimated that an alarming 75% of them will suffer from running-induced injuries at some point. Many of these injuries are preventable by maintaining good running form. This project develops a method to help runners track their running form. The developed methodology comprises of using an Arduino-based wearable device to collect accelerometer and gyroscope sensor data when the user is running, preprocessing sensor data to extract features closely related to running form, and using an artificial neural network (ANN) to analyze the extracted features to identify running form. The proposed features used in data preprocessing are novel. They can be easily extracted and will help reduce the complexity of the ANN. To train and evaluate the developed ANN, a dataset totaling 9568 strides in three running forms on different terrains was collected.

Experiments were also conducted to investigate the optimal ANN structures. The developed method can achieve 98% accuracy when identifying the three running forms.

Modeling Michigan West Nile Cases Amid Climate Change
Jasmine Wu
Troy High School
Troy, Michigan

Teacher: Rebecca Brewer

Scientists recognize that arboviruses and their respective vectors have been largely impacted by the effects of climate change, but attempts to accurately predict and model their relationship has proven notoriously difficult and widely varied across research papers. This is especially compounded as arbovirus transmission depends on both climate and intrinsic factors, such as avian carrier immunity and the prevalence of diseases in mosquitoes. Creating models that take these factors into account will require years of diligent and accurate surveillance methods and a thorough understanding of the transmission process that the scientific community hasn't mastered yet. How has climate change affected West Nile Virus incidence in Michigan?

Creating arbovirus prediction models for Michigan is especially difficult, as climate change has a surprising effect on precipitation and moisture levels -- two important environmental predictors of mosquito populations -- in the Great Lakes region. However, it remains vital, as West Nile Virus (WNV) (the focus of this research paper) can result in severe neurologic symptoms and fatality. By using mean monthly temperature, mean total precipitation in inches, and drought data, a model that predicts disease incidence has been created that accounts for 72.3% of the variation in annual WNV cases. Having such a model can provide public health authorities with information and preparation time and elucidate trends in order to effectively prevent West Nile Virus outbreaks exacerbated by climate change, especially during global pandemic and after climate scientists' warnings that climate change will increase the risk of pandemics.

Capturing Carbon Dioxide From the Air Using an Electrochemical Cell
David Yan
Charter School of Wilmington
Wilmington, Delaware

Mentor: Dr. Brian Setzler, University of Delaware

Our society's heavy reliance on fossil fuels for energy has led to increasing concentrations of carbon dioxide (CO_2) in the atmosphere and consequently climate crisis concerns. To avert the climate crisis, we need not only the deployment of carbon-zero renewable energies but also carbon-negative technologies - the removal of CO_2 from the atmosphere. In Year 1, I developed for the first time a low-cost electrochemical cell that can remove CO_2 efficiently from the atmosphere. The cell repurposes electrodes from the widely used commercial nickel metal hydride (NiMH) rechargeable batteries, ensuring long service life and manufacturability. A minimally optimized cell was experimentally shown to be able to remove CO_2 at a rate of 19 kg/(m^2*year) and an electricity cost of \$41/tCO_2 (ton of CO_2). In Year 2, I aimed to simulate and optimize the cell in order to reduce the electricity costs and increase the CO_2 capture rate. The simulation is based on a simplified 1-dimensional model that captures the most critical parameters including pH, CO_2 flux, and electric and ionic potential within the cell. My optimized cell can remove CO_2 at a rate of 184 kg/(m^2*year), which is nearly 10x the removal rate of my Year 1 cell. It has an electricity cost of \$16/tCO_2, which is lower than the \$31/tCO_2 electricity cost of the leading alternative technology from Carbon Engineering that has been funded by visionary investors including Bill Gates. These numbers suggest that my CO_2 removal technology has the potential to become a leader among carbon-negative technologies.

Novel Surveys of Substructure in Pulsar Glitch Morphology and Glitching Pulsar Populations
Christine Ye (3rd place, Physical Sciences)

Eastlake High School
Sammamish, Washington

Teacher: Casey Green

Observations of the rotation of pulsars, highly magnetized rotating neutron stars, have revealed a mysterious type of rotation anomaly: glitches, discontinuous events where the pulsar suddenly begins rotating faster. I study the substructure and population properties of pulsar physics through Bayesian methods in order to probe the microphysics of the superfluid and the behavior of matter at and beyond nuclear densities. I place upper limits on glitch sizes in 47 millisecond pulsars used for gravitational wave science, and find that there is a substantial minimum glitch size in these pulsars. Using a hierarchical approach, I infer best-fit parameters and overall evidence for models directly encoding information about the triggers of glitches, and find substantial support for mixed trigger models and limited dynamic range of scale invariance. I model the behavior of once-glitching and never-glitching pulsars in the lens of quasi-periodicity and stress accumulation by spindown, and find a number of these pulsars are inconsistent with quasi-periodic behavior, suggesting the pulsar glitch mechanism may not be universal. Finally, I look at the substructure of pulsar glitch behavior as a function of age, and find good agreement with an evolutionary picture informed by vortex creep and avalanche dynamics. These findings constrain possible mechanisms for glitch build-up, trigger, and recovery, and will not only serve to improve our understanding of the fundamental microphysics in the superfluids and crusts of neutron stars, but also improve the accuracy of pulsar timing measurements for use in gravitational waves, general relativity, exoplanet searches, and other fundamental astrophysics.

Smarter Cybersecurity: Detecting Obfuscated Malware using a Minimal Convolutional Neural Network

Boaz Yoo
Montgomery Blair High School
Silver Spring, Maryland

Mentors: Heidi Komkov and Daniel P. Lathrop, Institute for Research in Electronics and Applied Physics, University of Maryland

The Internet's presence is expanding in our lives as more devices like home assistants and other Internet of Things devices are presented. With increasing prevalence of daily exposure to the Internet, more facets of life become open to malicious cyber attacks. As malware behaviors have evolved, the need for effective detection systems has become urgent. Evasive malware have been designed to go undetected by traditional methods—static and dynamic analyses. A new detection scheme that evolves alongside malware evolution is needed to bridge the gap. In this work, we explore a novel approach to detect malware obfuscation, a form of evasive behavior, with computer vision and machine learning techniques. Specifically, we represent malware binary content from the Microsoft Malware Classification Challenge as grayscale images. We use a minimal convolutional neural network (CNN) optimized with the Hyperband algorithm to classify malware instances as obfuscated or non-obfuscated. We obtained a training detection accuracy of 99.89% and a testing detection accuracy of 98.16%. Our results show that even lightweight CNN architecture is a viable and effective solution for detecting obfuscation in malware. We believe that our malware classification method is a promising approach to combat evasive cybersecurity attacks. Our work encourages the possibility of widespread implementation of machine learning techniques in anti-malware systems for cybersecurity industries.

Association Between Radiological and Clinical Diagnosis in Pediatric Patients with Acute Respiratory Illness

Leonardo Zambrano Tapia
CIMATEC
Caguas, Puerto Rico

Mentor: Anabel Puig Ramos, Pediatrics, UPR-SOM

Historically, asthma has been known to be a problem concerning public safety; approximately 26 million Americans suffer from asthma. It is a chronic respiratory condition in which the lungs' airway become swollen upon exposure to changes in temperature, gases, dust or other irritants, or allergens such as mold and pollen. Short-Acting beta-agonist and inhaled corticosteroids are the two most common medications used to treat asthma, but at times there are exacerbations caused by viral or bacterial infections and require additional treatment. Even though bacteria are not always responsible for exacerbations, antibiotics are commonly prescribed to pediatric asthmatic patients even though they do not aid in improvement. This may cause bacteria to create an unnecessary resistance towards antibiotics and a burden to pharmaceutical's job to synthesize new drugs. Statistical and background information were collected to further understand the problem. Asthma may be underdiagnosed due to overimagining pneumonia which might lead to antibiotic overuse, unnecessary overexposure to radiation and overspending funds. There is a high-risk population in Puerto Rico that is threatened by this, and there are not many studies about this matter, so the goal is to understand this occurrence as well as bring awareness of it. Patients were selected from the hospital's medical records, admitted in June 2016-July 2017. Their demographic information was acquired and placed in Data Extraction Sheets. This data was analyzed with GraphPad Prism, calculating percentages, and using a Mann-Whitney test to compare patients prescribed with and without antibiotic treatment and their length of stay.

The Effect of Dopamine Synaptic Changes in the Inner Ear of *Porichthys notatus* on Seasonal Acoustic Communication

Chapin Zerner (2nd place, Biomedical Sciences)
Commack High School
Commack, New York

Porichthys notatus (plainfin midshipman) is a vocal fish found off the west coast of North America. Plainfin midshipman exhibit extreme seasonally-dependent alterations due to changes in reproductive activity. Winter females were hypothesized to demonstrate increased levels of dopaminergic activity, based on previous studies in dopaminergic shifts in rodents. Inner ear and hindbrain regions were analyzed through serial sectioned electron micrographs. Observed results showed an average of 5.3 ± 0.8 dopamine terminals per image stack in winter females, compared to 2.2 ± 0.7 in summer females ($p = 0.0049$). Additionally, the volume of dopamine terminals varied seasonally. On average, those found in winter midshipman females were 0.16 ± 0.05 μm^3, and those found in summer females were 0.11 ± 0.06 μm^3 ($p = 0.0435$). Dopamine contact with hair cells occurred in each winter specimen, while only one-third of summer specimens exhibited direct contact ($p = 0.0300$). From these results, dopamine was shown as a potentially inhibitory neurotransmitter. Due to its homologous brain structure to that of mammals such as humans, the malleability of dopaminergic processes of *P. notatus* may have implications to higher level organisms.

The Photocatalytic Single-Electron Oxidative Cyclopropanation of Ene-Ynamides with 2,6-Lutidine *N*-Oxide: Synthesis of Bicyclic Amides

Jason Zhang
Gatton Academy
Bowling Green, Kentucky

Mentor: Dr. Yongming Deng, Indiana University–Purdue University Indianapolis

In the past decade, photocatalysts have been used to create important biomolecules by facilitating electron transfers between different compounds in the presence of visible light. Photocatalysts function similar to chlorophyll pigments, which absorb sunlight to excite and transfer electrons in photosynthesis. In 2016, the Nicewicz group reported that alkenes can undergo single-electron oxidation in the presence of a photocatalyst and sunlight to form alkene radical cation intermediates, which further reacts to create essential biomolecules. However, the application of using photocatalysts to oxidize alkynes had not been successful due to considerably

higher oxidation potential of alkynes than alkenes. In this work, we present a novel strategy of lowering this barrier by reacting alkynes with the compound 2,6-lutidine *N*-oxide and a photocatalyst under blue light to synthesize a variety of useful bicyclic amides. These nitrogen-containing bicyclic compounds are crucial intermediates of many biological drugs like the antidepressant milnacipran. Previous synthesis of these compounds requires harsh reaction conditions and precious metal catalysts, a pharmaceutical concern as some metal residuals may remain in the drugs. However, this research presents the metal-free and sustainable synthesis of these important biomolecules. The structures and purities of our synthesized compounds have been verified by Nuclear Magnetic Resonance (NMR) spectroscopy. In addition, factors affecting the yields of these photocatalytic reactions, including solvent effects and substituent effects, have been analyzed. This research represents an efficient, metal-free and sustainable synthesis of a variety of important pharmaceutical precursors using visible light.

NJSHS 2021 Poster Presenters

Biomedical Sciences

William Bernfeld
Patryk Dabek
Lela DeVine
Mia Dittrich
Caledonia Grant
Anish Gupta
Eleanor Jung
Shriya Kapoor
Aditya Koushik (3)
Richard Liu
Atulya Mandyam
Kalina Namikas
Shruthi Ravichandran
Harnoor Sachar (1)
Aryan Singh
Chaeun (Christine) Song
Ivy Wang
Weixuan Yan (2)

Chemistry

Sayge Barkley
Amelia Curia
Allison Havard
Rishi Hazra
Caleb Kim
Emma Price
Aaditya Saha (1)
Paige Sherman (3)
Suvin Sundararajan (2)
Anjali Vadlamudi
Nicholas White

Engineering & Technology

Alexander Bell
Victor Cai (2)
Vashty González
Audrey Gruian (1)
Gabriel Gurule (3)
Alexis Harvey
Shraman Kar
Kevin Li
Alan Ma
Ashraf Mansour
Jennifer Oettinger
Jordan Prawira
Mikul Saravanan
Kurt Schelzig
Saraswati Sridhar

Environmental Science

Claire Bogen
Brice Brown
Meaghan Caron (2)
Claire Gu
Jadyn Henry
Maya Irvine
Mithra Karamchedu
Shreya Khullar
Aaron Lewis
Grace Mango
Elaina McHargue
Rithika Narayan
Yash Narayan
Gitanjali Rao (1)
Bria Roettger
Isabel Ross
Austin Shinzato
Lynn Tao
Lana Van Note (3)
Eleanor Veazey

Life Sciences

Shivani Babu
Megan Bime
Ella Buhlke
Chayse Chandler
Beverly Eborn
Kara Fan (2)
Karshana Kalyanaraman
Jaeah Kim
John Lin (3)
Marissa Martinez
Margaret Mattson
Samira Nassi Celaya
Alexander Patti

Khushi Pola
Juni Polansky
Laboni Santra (1)
Sreeram Satish
Nicole Stover
Patrick Wahlig
Kesara Wein
Isabella Wiebelt-Smith

Mathematics & Computer Science

Grace Chen
Ronald Cheng
Lauren Choi (2)
Lisa Crawford
Ameya Jadhav
Daniel Joy
Conan Lu
Isha Narang
Tejas Prabhune
Itamar Pres (1)
Josh Sanyal (3)
Lauren Schmidt
Arvind Seshan
Arjun Singh
Edmund Sumpena
Ethan Wang
Jeremy Zhou

Medicine & Health/Behavioral Sciences

Vardhan Agrawal
Atreyus Bhavsar
Olivia Canter
Ava Chae
Yunseo Chung
Srihitha Dasari
Hannah Gao
Nathaniel Gao
Eyrin Kim (2)
Shan Lateef (3)
Rayna Malhotra
Eden Maxwell
Molly McNulty
Safiya Sankari
Alay Shah
Hannah Skwarek
Ava Steger
Simran Tippabhatia
Vivian Yee (1)
Jaden Yun

Physical Sciences

Kenneth Choi (2)
James Gonzales (3)
Ramzi Saber (1)

NJSHS 2021 Poster Presenter Abstracts

Automated Assessment of Spaceflight-Associated Neuro-Ocular Syndrome via Incidence of Papilledema and Cotton-Wool Spots

Vardhan Agrawal
Cupertino High School
Cupertino, California

Teacher: Eric Ferrante

The purpose of this project is to develop an algorithm to automatically diagnose Spaceflight-Associated Neuro-Ocular Syndrome (SANS) to promote early detection of the condition. SANS has been linked to Long Duration Space Flight (LDSF) and is most regularly observed on the International Space Station (ISS).

The goals of this study are to:

(a) Design and develop lightweight machine learning models to provide diagnostic analysis in conjunction with supplementary visual information, such as optic disc location annotations, on fundus images of space crew.
(b) Create an extensible platform which allows further development in the automated assessment of SANS using fundus images.

The proposed method to assess SANS uses a series of machine learning models with individually assigned tasks. There are three model types used in this study: classification, segmentation, and object detection. Combined, the proposed models will provide diagnostic information about the image and provide medical professionals visual information to assist in diagnosing SANS.

The models achieved high levels of accuracy, above 92% on the training set and above 87% during testing on randomly selected validation subsets from the STARE, IDRiD, and CHASE datasets. Combined, the validation set consisted of 103 images, including augmentations, from professionally obtained images.

Overall, the presented solution has the potential to solve a large-scale problem using cutting-edge technology. It is the first step in the detection of SANS, a largely unexplored space. It is practical for use on-board LDSF, and it can be adopted by NASA to help improve the safety of spaceflight for space crew.

Effects of High-Fat Diet on Phosphoprotein Enriched in Astrocytes-15kD (PEA-15) mRNA and Protein Expression in the Cerebrum of Mice

Shivani Babu
Auburn High School
Auburn, Alabama

Teacher: Jacque Middleton

Mentors: Dr. Robert Judd and Dr. Emily Graff, Auburn University

Phosphoprotein expressed in astrocytes-15kDa (PEA15) is an intracellular adaptor protein that affects cellular fate. PEA15 is ubiquitously expressed, and highly expressed in the central nervous system, including the brain. In type 2 diabetes mellitus patients and in rodent models of insulin resistance, PEA15 messenger RNA (mRNA) and protein are increased in peripheral tissues (skeletal muscle and adipose). However, it is unknown if changes in PEA15 are a result of insulin resistance, or if they contribute to the underlying mechanism. Additionally, it is unclear if changes in insulin resistance affect PEA15 in the brain. This study's objective was to determine if PEA15 mRNA and protein expression changes in the cerebrum of mice if fed a high-fat diet (HFD) during the development of insulin

resistance. Male C57BL/6 mice were fed either a chow diet or HFD for a duration of 1-week or 12-weeks. Cerebral tissue was collected for mRNA and protein extraction. PEA15 protein and mRNA expression were assessed by Western Blot and Real Time Quantitative Polymerase Chain Reaction (RT-qPCR), respectively. There was no significant change in mRNA or protein expression owing to duration or diet. However, an increasing trend was found in mRNA expression and a decreasing trend occurred in the protein expression.

Development of Bioplastic from Keratin

Sayge Barkley
Baker High School
Baker, Montana

Teacher: Linda Rost

A majority of plastic is currently nonbiodegradable and is plaguing the planet, but it is essential for many processes and products. The goal was to create a biodegradable plastic prototype using extracted feather keratin. Feathers are ideal because they do not have many commercial uses and they are a byproduct from poultry farms. Keratin was extracted using chemical processes then combined with a plasticizer glycerol. It was difficult to extract adequate amounts of feather keratin to make bioplastic samples, so tilapia keratin from a supplement pill was also used to make bioplastic to compare. Tilapia fish scales are a large source of waste in the seafood industry. The prototypes all had differences in physical appearance, viscosity, and yield. The feather keratin produced a thin, flaky bioplastic. The tilapia keratin bioplastic was produced with different amounts of glycerol. The lower amounts of glycerol produced a brittle bioplastic and the higher amounts produced a more viscous and liquidy bioplastic. The prototype with 25% glycerol produced the best bioplastic, which was tacky and cohesive. Future research and experimentation is needed to solve problems with useability and durability. The texture and malleability of the keratin bioplastic will need to be adjusted to compensate for regular plastic use.

Optimization of a Venturi Flow Mechanism for Gas-Transfer Applications

Alexander Bell
Kealakehe High School
Kailua Kona, Hawaii

Teacher: Justin Brown

This paper investigates the optimization of venturi-type funnels for applications requiring compact, low-power gas transfer mechanisms. To start, computational flow design (CFD) software was used to identify a set of nine funnels within broad parameters determined through virtual wind-tunnel simulations. Each configuration had a throat diameter (TD) between 5-10mm and a diverging angle (DA) between 7° and 17° degrees. Models were 3D printed out of ABS filament and smoothed in an acetone vapor bath. Manufacturing precision was verified to one-tenth of a millimeter. Utilizing a custom testing-rig with a 28mm fan for airflow and an MQ-3 gas sensor for readings, both gas-injection capability, and airflow distribution were tested. Recurrent patterns within test data revealed a “Goldilocks” range within the parameters of 7mm - 8mm TD and 7° - 12° DA in which gas concentration readings from the MQ-3 sensor were at optimal levels. Statistical analysis confirmed a statistically significant difference in effectiveness within this range. The value of these results is not limited to gas-delivery applications. The configuration’s scalable nature gives it the potential to fit in practically any appropriate context. Results suggest that the preceding optimization could play a catalytic role in improving everything from life-saving ignition interlock systems to methane gas-detection devices and a variety of other existing and innovative technologies. Current

further research includes the testing of a venturi amplification system within an existing commercial gas-leak detection device.

Non-Canonical Base Pairing in Self-Assembling DNA Crystals

William Bernfeld
King School
Stamford, Connecticut

Mentor: Simon Vecchioni, New York University

The scientific community has long recognized the four naturally-occurring nucleobases as the universal genetic language. However, this four-base model has recently been turned on its head with the development of "hachimoji" nucleic acids, which use up to eight bases. Four new synthetic components have been incorporated into a variety of sequences. These sequences, in turn, have been used to encode basic information and to construct a wide variety of crystals and nanocages. In this investigation, we furthered our understanding of hachimoji DNA by using the Python-based Hierarchical ENvironment for Integrated Xtallography (PHENIX), the Crystallographic Object-Oriented Toolkit (COOT), and ChimeraX to simulate a base pair between cytosine and 5-methyl isocytosine. This virtual base pair is situated at the center of a DNA strand derived from a previously-designed sequence, developed roughly 11 years prior. This pairing is considered degenerate because its components do not normally form hydrogen bonds. However, it shows coherence within the digitized sequence, and therefore suggests that the pair can exist in the real world. Should future research reveal further evidence of its existence, this development has tremendous implications for the biochemical sciences, e.g., molecular computing, genetics, and immunology. Because the new base pair may be capable of encoding peptides using non-proteinogenic amino acids, our findings may be used for the development of new, unique proteins. These molecules, encoded using hachimoji nucleic acids containing the cytosine-5-methyl-isocytosine base pair, may prove effective in the treatment of genetic and/or metabolic illnesses such as diabetes, anemia, and cancer.

The Spread of Macroscopic Droplets from a Simulated Cough with and without the Use of Masks or Barriers

Atreyus A. Bhavsar
Blake High School
Minneapolis, Minnesota

Mentor: Abdhish R. Bhavsar, M.D.

One main challenge during the COVID-19 pandemic is the lack of safety measures and guidelines to reduce the risk of viral spread during gatherings. This study was conducted to evaluate the distance of oral and nasal droplet spread in a model that simulates coughing and sneezing in a public setting, specifically a school setting, to guide students, faculty and staff with safety measures and guidelines to reduce droplet spread. Several models were prepared to observe simulated respiratory droplet spread in places such as the classroom and cafeteria, in which students would be more susceptible to contracting a virus since masks cannot be worn while eating. For all trials, a 2.54 cm balloon with 0.3 ml of diluted fluorescent paint was placed inside a mannequin head and inflated outward from the mannequin's mouth at 5 psi until it burst. A black light was used to visualize the expelled fluorescent macroscopic droplets. Wearing a mask properly over the nose and mouth and using a barrier around a personal eating area without a mask was extremely effective in reducing droplet spread. These studies helped develop innovative measures for barrier design. Without face masks or barriers, social distancing proved to be ineffective. In conclusion the most effective way to prevent droplet spread during activities where masks simply cannot be worn, such as eating, is to apply barriers between the individuals. Applying barriers with innovative measures and wearing masks successfully prevented macroscopic droplet spread and can help safely return students and faculty to school.

Changes in Bile Acid Signaling During Obesity and Prebiotic Treatment

Megan Bime
Catalina Foothills High School
Tucson, Arizona

Teacher: Tiffanie Bialis

Mentors: Rachel Meyer and Dr. Frank Duca

Obesity is a condition characterized by excessive body fat accumulation that occurs in part due to increased calorie consumption. Obesity affects nearly 42% of Americans and leads to increased risk of metabolic diseases like type-2 diabetes. The gut microbiome is key to regulating whole body metabolism and is known to contribute to the development of type-2 diabetes and obesity. The gut microbiome can also influence bile acid homeostasis that may impact obesity risk. Bile acids are metabolites produced by the liver to facilitate the absorption of fats, and both obesity and altered gut microbiota compositions are associated with dysregulated bile acid pool composition. Three treatment groups of twelve mice were fed either high-fat, high-fat plus oligofructose, or chow diets for nine weeks. Bile acids were then examined from four sites in the rats—the liver, small intestine, portal vein, and colon—to look for significant changes between high-fat and chow diets as well as the effects of the prebiotic oligofructose, known to reduce adiposity and beneficially alter the gut microbiota. The high fat diet was found to alter the abundance of several bile acids, such as cholic acid and chenodeoxycholic acid, and this effect was reversed with oligofructose supplementation. These results can provide new hypotheses in future studies targeting specific bile acids towards potential novel therapies for the treatment of obesity, as future studies may test the effects that treatment with specific bile acids have through direct infusion.

Geographic Features Relationship with Nuclear Radiation Distribution

Claire Bogen
Nile C. Kinnick High School
DoDEA Yokosuka, Japan

Sponsor: Kerry Stevens

This project analyzes the distribution of nuclear radiation in the surrounding areas of the Daiichi Nuclear Power plant located in Fukushima, Japan. It compares soil samples taken from various locations with differing geographic features (land masses, water, etc) in hopes of finding a patterned relationship concerning a place's topographic characteristics and the amount of radionuclides found within its top 8 inches of soil. It was hypothesized that areas containing inland water features (rivers, waterfalls) would have higher levels of radioactivity. Soil samples were collected from Ibaraki and Hayama, Japan, and measured using a geiger counter. Through the use of a one way Anova calculator, variances within and between groups were calculated. With a P value over .05 (P=.33), the results were not able to reject a null hypothesis. However, the original hypothesis was supported, as dirt taken from inland areas where waterfalls or rivers were present had the highest average levels of radioactivity recorded through a geiger counter (mean CPM Avg.=17.33). The lowest levels of radiation were recorded in high altitude, mountainous locations (mean CPM Avg.=13). The results support the theory that aqueous processes are the main cause of the redistribution of radionuclides in soil.

Dominant feeding nature of Cnidarian-dinoflagellate symbiosis and effects of minerals on the coral model *Aiptasia*'s growth and health

Brice Brown

Stuttgart High School
DoDEA Stuttgart, Germany

Teacher: Daniel Coapstick

Advisor: Jason Baer

Coral reefs have been suffering in recent years. One of the causes behind reduction is likely the poor health of ecosystem engineer cnidarians, such as corals, sea anemones, and sponges in an already nutrient-poor environment. Understanding the preferred feeding nature of symbiotic cnidarians and surrounding mineral compositions can help reinvigorate and improve tropical reefs that hold a significant amount of biota. Through this experiment, the optimal feeding and minerals will be revealed by using *Aiptasia pallida,* a commonly used sea anemone for coral research. Other researchers in the field will use this data to grow their Aiptasia to ease coral research efficiently. Light levels are measured on five scales, “always-on,” “always-off,” and eight, twelve, and sixteen-hour on cycle with intermittent addition of brine shrimp to stimulate heterotopic feeding. Iron, copper, nitrate, and phosphate were chosen to supplement a twelve-hour light and dark cycle complemented by brine shrimp feeding, which provides a more realistic environment without the introduction of confounding variables like those in a mesocosm.

Cross-species transmission of *Drosophila melanogaster* Nora virus in other Drosophila species and effect on geotaxis

Ella Buhlke
Central City High School
Central City, Nebraska

Teacher: Chelle Gillan

This study was performed to determine the cross-species transmission of the *Drosophila melanogaster* Nora virus in other Drosophila species and its effect on geotaxis. There are millions of known viruses, and new ones are discovered every year. A major source of new viruses is epizootic and enzootic animal viruses, seen when viruses typically occurring in animals adapt and mutate to infect humans. COVID-19 is an example of one of these host-switching viruses, as it originated in bats (Ji, 2020). The Nora virus is a picorna-like virus whose only known pathogenic effect is a geotaxis defect. The cross-species transmission of this virus in fruit flies can be used to help scientists better understand host-switching in other viruses. It was predicted that the virus would infect the other species of Drosophila and that it would have an effect on their geotaxis. To test this hypothesis, Nora virus-positive males were allowed to defecate on fly food. Once they were removed, negative males and negative virgin females of each species were added to the vials. The geotaxis of their offspring was measured before they were collected for RNA analysis. RT-PCR was performed to determine infection, and all species tested positive, showing the Nora virus to be a host-switching virus. Geotaxis results showed a defect in the experimental groups in comparison to the control indicating that the virus does have a pathogenic effect on the other species. Learning more about cross-species transmission has increased importance in today’s world as the number of zoonotic viruses increases.

Creating a Low-Cost Narrowband Radar with Simultaneous Distance and Velocity Sensing Using Software Defined Radio (SDR) Interferometry

Victor Cai (2nd place, Engineering & Technology)
Parkland High School
Allentown, Pennsylvania

Mentor: Jon Kraft, Analog Devices Inc.

This project achieved both high accuracy and low cost in narrowband design by combining the unpopular Multiple Frequency Continuous Wave (MFCW) radar algorithm with two low-cost Software Defined Radios (SDR), as well as another solution using Frequency Shift Key (FSK) radar with a single SDR. The MFCW design is an independent research, while the FSK is mentor supervised research with preliminary but promising data.

A traditional Pulse or FMCW radar needs 1GHz bandwidth (BW) to achieve 15cm resolution for short range applications, making a typical SDR's 4-60MHz BW far from adequate for distance sensing. However, in this project, two new interferometry radar solutions are demonstrated to make distance and speed sensing possible using bandwidth-limited SDR, where phase delta from two different frequencies is used to calculate target distance. Because of SDR's software approach, minimal hardware is required besides the SDR unit, which lowers the bar to <$500 for amateur radio enthusiasts to build a radar system. Despite a lack of applicable publications on MFCW radar, a distance sensing algorithm was successfully created to correct erroneous results by transposing phase domains. This new concept opens the doors to many short-range radar applications using the emerging low power and low cost SDR technology. The super low 4KHz bandwidth required by MFCW radar (instead of 1GHz) also led to significantly reduced interference to other wireless devices, and minimum electrical/computing power. A simple $60 Raspberry Pi minicomputer is more than adequate for processing data and powering the 2 SDR units through its USB ports.

Birds of a feather age together: Telomere dynamics and social behavior predict lifespan in female Japanese quail (*Coturnix japonica*)

Olivia Canter
Byram Hills High School
Armonk, New York

Teacher: M. Gulick

Mentor: Dr. Mark Haussmann, Bucknell University

Longevity is a major focus in biomedical exploration and evolutionary ecology, but little is known about the underlying processes that cause variation in lifespan. Telomere shortening may be one such mechanism; the erosion of this "biological clock" at chromosomal ends can affect organismal aging. Other factors, such as social interaction, may also influence longevity. Here, 36 female Japanese quail from six family groups were studied to explore how cellular aging mechanisms and social factors influence lifespan. Telomeres were analyzed with the Telomere Restriction Fragment assay, and behavioral data, collected through pecking interactions, was evaluated to determine dominance, aggression, and coalition status. Telomere loss in the first and last year of life significantly predicted lifespan, signaling the key roles that early and late life play in survival. Telomere length at 11 and 23 months of age was significantly related to longevity, proposing a biomarker of lifespan. Within the six families, family had a significant correlation with telomere length at one month, indicating a heritable component for initial telomere length. Furthermore, dominance significantly predicted increased lifespan, while aggression significantly predicted decreased lifespan, suggesting that being dominant with a light touch maximizes survival. Coalition status was significantly related to telomere loss, perhaps explaining why coalition members exhibited increased lifespan. Finally, family was significantly related to submissive behavior, proposing a heritable component of vulnerability. Ultimately, this groundbreaking longitudinal study provides a window into cellular and social factors that can be targeted to prevent or delay the aging phenotype, and in turn, maximize survival.

Fallopia Japonica as an Alternative Fuel Source to Remediate the Spread of Invasive Species

Meaghan Caron (2nd place, Environmental Science)
Bangor High School
Bangor, Maine

Japanese knotweed (*Fallopia japonica*) is a highly invasive plant which has increased in severity over the past century. By dominating native habitats, the species causes rapid reductions in biodiversity while damaging agriculture and economy by compromising the foundation of buildings and ecosystems. To eliminate these setbacks and put its abundance towards good use, this study explores Japanese knotweed as an alternative fuel source. Biomass wood pellets are a proposed solution which have risen in popularity due to their clean, renewable energy. Despite halted lab access due to COVID-19, a method was developed for making homemade wood pellets from Japanese knotweed using a kitchen oven, Cuisinart blender, vegetable oil, and wooden cutting board mold. After qualitative analysis of the pellets, it was determined that high heat and vegetable oil additives were necessary components of a successful biomass wood pellet. Using this criteria, the Japanese knotweed pellets were replicated for testing of moisture content, ash content, and calorific value. By comparison of the Dry Biomass and commercial wood pellets—industrially produced at UMaine—the homemade pellets showed superior performance in energy production. This was associated with a visibly lower moisture content, which allows for the high combustion efficiency of traditional wood pellets. Although the ash content was greater than that of the Dry Biomass, this may be explained by the at-home pellet making process. A larger sample size of pellets is needed to affirm statistical differences, but these data serve as promising preliminary results for Japanese knotweed as an alternative fuel source.

When the Pandemic Creates Behavioral Changes and Economic Crisis: The COVID-19 Pandemic and the Implications for Policy Making

Ava Chae
Manhattan High School
Manhattan, Kansas

Sponsor: Janet Stark

The COVID-19 pandemic is no longer simply a “health crisis” but seems to have far-reaching impacts and implications as well. The pandemic has led to an unprecedented decline in consumer confidence (demand shock) as people quickly changed their spending behavior to focus on basic needs. In response, the government has taken actions to boost consumer confidence and spending through stimulus packages and other aid. This research uses a public database of private sector data with current information on consumer spending and employment and implements Abraham Maslow’s psychological theory, the hierarchy of needs, and Keynesian economics to explain consumer spending behaviors and the U.S. government’s response to the pandemic. Three hypotheses are developed and tested using regression analysis. First, the findings of the regression discontinuity show significantly higher spending in industries fulfilling basic needs than in nonessential sectors. Second, a causal relationship was found between aggregate demand, more specifically consumer spending, and employment, revealing the distinctness of the pandemic-caused recession driven by coronavirus fear. The final regression discontinuity was tested to observe the effect of stimulus checks (CARES Act) on spending and economic recovery, revealing positive impacts of boosting aggregate demand. This study provides evidence that while high-income households and individuals were the least impacted by the pandemic regarding employment, they showed the most dramatic changes in spending behavior. The study provides discussions and implications as to how to mitigate the effects of the COVID-19 recession in the U.S.

Assessing the Effectiveness of the *Hericium erinaceus* Extract as Acetylcholinesterase Inhibitors

Chayse Chandler
North Carolina School of Science and Mathematics
Durham, North Carolina

Mentor: Dr. Kim Monahan

Alzheimer's Disease (AD), a type of dementia, is attributed to the overproduction of the amyloid-beta (Aß) protein caused by the cleavage of the amyloid precursor protein. This project focuses on deriving therapeutics to control the Aß protein by finding an effective acetylcholinesterase (AChE) inhibitor (AChE-I). Research indicates that low levels of acetylcholine are correlated with high levels of the Aß protein, thus, an AChE-I will hypothetically decrease the level of the Aß protein. The most effective known AChE-I is galantamine, an alkaloid isolated from *Lycoris radiata*. This particular project will focus on assessing the ability of the extract isolated from *Hericium erinaceus* as an AChE-I. The first paralysis assay with model organism *Drosophila melanogaster* demonstrated that high concentrations of the *H. erinaceus* isopropyl extract significantly increased paralysis in comparison with isopropyl alcohol. This suggests that the extracts are toxic, a characteristic of AChE-Is. An Ellman's Assay concluded that all the galantamine concentrations and the 0.05g/mL concentration of the extract significantly decreased the AChE concentration ($p<0.01$). The second experiment of wildtype *D. melanogaster* and lower concentrations demonstrated no significance with the two lowest concentrations of galantamine and extracts compared to alcohol, which suggests the concentrations are safe.

Developing a Voice Recognition Program for Natural Rescue Using Short Time Fourier Transforms and Deep Learning Convolutional Neural Networks

Grace Chen
Catlin Gabel School
Portland, Oregon

Teacher: Joey Grissom

This study focuses on developing a sound recognition program that utilizes convolutional neural networks to assist search-and-rescue (SAR) missions. While a few past studies have developed SAR technology using image recognition techniques to identify human forms in the wilderness, comparatively fewer studies have used sound recognition techniques for the same purpose. Image recognition techniques may be inefficient when the traversed terrain contains dense forests or cliffs that obstruct human forms, but this constraint is not applicable to sound recognition techniques. In this project, a convolutional neural network was used to identify human voices from environmental sounds using the MATLAB software program. Two hundred environmental and human sound recordings were inputted into the neural network AlexNet to train it to distinguish between human and environmental sounds. AlexNet underwent several training and testing periods, each with a different number of training epochs applied. The neural network's accuracy and training time was recorded for each of 20 trials. Finally, the epoch number that resulted in the optimal balance between high validation accuracy and low training time was determined. The results of this study indicate that the optimal epoch number is 10, which results in an average neural network validation accuracy of 94.5% and an average training time of around 88 seconds. This study could act as a stepping stone for future voice recognition developments in the SAR field. Follow-up studies could involve different neural networks, and this sound recognition program could potentially be modified to recognize specific environmental sounds.

Tackling the COVID-19 Data Crisis in NY State: Application of the Poisson Process with Considerations of Alternate Data Sources

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Plainview Old Bethpage John F. Kennedy High School
Plainview, New York

Teacher: Ray Tesar

Mentor: Evan Lander

As of November 2020, more than 33 million cases of COVID-19 have been recorded in the United States. In the midst of a public health crisis, the US faces another challenge: a COVID-19 data crisis. As a result of decentralized data collection and patchy state datasets, standard epidemiological models, which are used to analyze historical case data and guide public policy, such as the Susceptible-Infected-Recovered (SIR) model are difficult to produce. This paper reviewed several touted alternate data sources, finding that mobility data released by Apple and google was most useful, resulting in a machine learning model that was used to predict the percent change in cases in the next two week period with an average variance score of 0.77 produced by a K-Fold Cross Validation. To add randomness to the model, this paper considers the use of the poisson process, a stochastic modeling technique that simulates interarrival times of events, to gain a confident understanding of the bounds of the spread of the virus. Simulations were produced using the Poisson Process and the output of the machine learning model, resulting in a two week case prediction (outside the dataset the model was trained on) with 25.3% ± 3.74% error in line with the 0.77 explained variance score. This suggests that mobility data is worth investigating for use in COVID-19 modeling, and that further improvements to the model may provide an effective way to guide policymakers and estimate the short term effects of mass travel events.

Constructing General Hamiltonian Ground States on a Quantum Computer Using the Projected Cooling Sensor Algorithm

Kenneth Choi (2nd place, Physical Sciences)
Ridgefield High School
Ridgefield, Connecticut

Mentor: Dr. Dean Lee, Michigan State University

Quantum computers have the potential to find the properties of complex many-body systems that classical methods cannot examine. One such property is the ground state, a system's lowest energy configuration. Lowest energy configurations can model the solution to optimization problems, which are essential to solve in artificial intelligence, cryptography, bioengineering, and more. However, current quantum algorithms that attempt to reconstruct ground state wave functions have low fidelity and are not robust against noise. To this end, we introduce the projected cooling sensor algorithm, which accurately reconstructs the ground state of any general Hamiltonian, the energy operator of a system, to solve the quantum ground state preparation problem. For low-dimension Hamiltonians, the projected cooling sensor algorithm reconstructs the ground state with a relative error of 0.0001 or less. For high-dimension Hamiltonians, multiple iterations of the projected cooling sensor algorithm exponentially decrease the error of the reconstructed ground state. We find that on a quantum computer, the reconstructed ground state has nearly 100% overlap with the exact ground state. The projected cooling sensor algorithm can be applied to a wide range of physical systems, including nuclei, bulk materials, superconductors, Ising models. Moreover, the projected cooling sensor algorithm can be applied to any energy-minimization problem relating to computer science, from developing advanced cryptographic algorithms to modeling protein folding to establish more efficacious cancer treatments. When simulated on a quantum computer, the projected cooling sensor algorithm has the potential to achieve quantum supremacy over classical computations for any system.

Automated Breast Cancer Detection Pipeline via Mitotic Cell Recognition Using Artificial Intelligence

Lauren Choi (2nd place, Mathematics & Computer Science)
Walter Johnson High School
Bethesda, Maryland

Mentor: Dr. Handuo Shi, Stanford University

The mitotic rate, a measure of how quickly cancer cells are dividing, is challenging for pathologists to determine due to the large number of cells shown in histological images, the scarcity of mitotic cells among them, the variety of nuclei shapes in different stages of mitosis, and the visual similarity of mitotic cells to non-mitotic cells like cells undergoing apoptosis and other abnormal cells in cancerous tissue. In this study, a neural network based pipeline for detecting rare mitotic cells was developed and assessed for accuracy. This was achieved with 2 novel developments in this study: first, a sliding window scheme that enabled the mapping of high probability mitosis locations, and secondly, a training data augmentation strategy that took advantage of the model's own false predictions to improve performance. The runtime of the pipeline is approximately an hour, which is well within the current 2.7-day turnaround time for pathologist interpretation sign-off. This pipeline achieved an F_1 measure of 0.400, outperforming the best result of the MITOS-ATYPIA-14 contest ($F_1 = 0.356$). Such an automated tool improves the efficiency and consistency of mitotic rate determination, and expedites turnaround time to patients which is critical for making time-sensitive clinical decisions. In addition to expanding to other types of cancers, the detection and training strategy developed here can be used for the automated distinction between similarly appearing objects in security applications, such as distinguishing imposters in security camera footage or between friend and foe vehicles, tanks, or airplanes from aerial surveillance footage.

Estimating the Reproduction Number of and Percentage Immunity Required for Herd Immunity Against COVID-19

Yunseo Chung
The Governor's School for Science and Technology
Hampton, Virginia

Teachers: Dr. Ford and Ms. Feygelson

COVID-19 has ravaged the world since early 2020. Lives have changed completely across the world – and people wait anxiously for normalcy to return. The purpose of this study is to estimate how many people need to be vaccinated to control and overcome this pandemic. Prior estimation about the minimum vaccination rate was largely unknown and often varied wildly. Using the SEIR (Susceptible - Exposed - Infectious – Recovered) model, differential equations, and publicly available CDC data on COVID-19, I estimate the reproduction number (R_0) of COVID-19 and the minimum vaccination rate for each state and nation to achieve herd immunity. Based upon COVID-19 daily data between Oct. 2020 and Dec. 2020, the R_0 value for the US was determined to be 11.6. The corresponding minimum vaccination rate to achieve herd immunity was 91.3% of the population. State values of R_0 hovered around the national value – as did the estimation of the required vaccination rate, varying between 90% of the population in North Dakota to over 93% in Vermont. As the country strives to put an end to the COVID-19 pandemic, this research contributes to the battle against the pandemic by providing scientific model and approach for the estimation of the minimum vaccination rate.

The Thickness of a Coin if The Probability of The Coin Landing on Its Edge is One Third

Lisa Crawford
Governor French Academy
Belleville, Illinois

Mentor: Mrs. Stewart

I did this experiment, because I am interested in math. When I think about probability and math projects, I think about coins and cards, so I chose coins. The experiment was conducted by first cutting a dowel rod into different thicknesses. An EV3 robot was used to flip the coin, which was assembled by various people. Instead of programming the robot on a computer, the robot was programmed by going to the settings on the robot. One of the settings on the robot was motor control, upon which the up button would be hit and the arm would be flipped. Each coin was flipped sixty times and it was recorded which side that the coin was landed on.

During the research, a formula was developed that said that the thickness was equal to the radius of the coin divided by the square root of two. The formula was found by substituting different equations into other equations until we got an equation where the thickness equaled something. From my results it was concluded that for a coin with a diameter of 2.54 cm, the thickness needed to be 0.9 cm.

Addition of Silica Nanoparticles in Epoxy for an Alternate Underwater Hardware Pressure Vessel

Amelia Curia
Colonia High School
Colonia, New Jersey

Teacher: James Danch

Computer hardware used in underwater drone technology needs to be sealed from water, as well as withstand ocean pressures and must be able to dissipate heat generated by electronic components. The epoxy currently used to seal the hardware suffers from cracking under pressure. It was hypothesized that the addition of silica nanoparticles to epoxy hardware sealant will improve structural integrity without decreasing its heat-dissipating properties. Three tests were conducted on epoxy samples with varying amounts of silica, the control of pure epoxy, and two treatments containing 25% and 50% silica to epoxy ratio. The samples were tested to determine their breaking points, and allow for measurement of the structural integrity. Testing demonstrated the presence of silica nanoparticles enhances the strength of the epoxy, allowing for a breaking force of 957 newtons at a displacement of 0.605 cm exceeding that of control samples. Heat transfer tests demonstrated that the silica-doped group had a mean of 0.6°C temperature increase higher than the control, indicating a lower heat capacity and greater heat dissipation abilities. Results suggest that the addition of silica nanoparticles may strengthen epoxy sealant while enhancing the heat dissipating property of the metal surrounding computer hardware in undersea drones.

Exploiting Metabolic Reprogramming In Liver Cancer: Mitochondrial Membrane Potential (Δψm) Response To Selective Atp Hydrolysis Inhibition

Patryk Dabek
Bergen County Academies
Hackensack New Jersey

Mentors: Alyssa Waldron and David Reeves, Nano-Structural Imaging Lab, Bergen County Academies

Hepatocellular carcinoma (HCC), is the third most common cause of cancer-related death worldwide. Over 80% of HCC patients suffer from underlying liver diseases that complicate treatment and lead to poor prognoses. Unlike healthy cells, which utilize the electron transport chain to generate energy and maintain their mitochondrial membrane potential (ΔΨm), cancer cells utilize aerobic glycolysis to generate energy and therefore must rely on an ulterior method to maintain ΔΨm— ATP Hydrolysis. This project focuses on exploiting this hallmark to target cancer's proliferation-focused metabolism. It was hypothesized that if ATP Synthase's hydrolyzing mode of homeostatic proton-pumping was inhibited, then ΔΨm would collapse in cancer cells, releasing pro-apoptotic proteins into the cytosol and inducing apoptosis. To test this hypothesis, the effect of selective inhibition of ATP Hydrolysis in HepG2 cells was analyzed. Flow cytometry and imaging data showcase that ΔΨm depolarization does occur; furthermore, this depolarization leads to the release of pro-apoptotic agents by the mitochondrial permeability transition pore. Analyzing changes in metabolic activity, it was elucidated that the treatment led to

mitochondrial dysfunction. This effect was supported by statistically significant increases in reactive oxygen species, decreases in glucose uptake, and decreases in intracellular ATP levels ($p < 0.05$). These changes, alongside increasing levels of pro-apoptotic proteins in the cytosol, culminated in Caspase 3/7 dependent apoptosis and decreased proliferation. The findings of this study suggest $\Delta\Psi m$ depolarization as a novel target in HCC and its efficacy as a therapeutic option in a growing array of metabolic treatments for cancer.

Improving Multiclass Classification of Alzheimer's Disease using Cortical Volumetry and Inter-Cortical Ratios as Combined Markers

Srihitha Dasari
Denmark High School
Alpharetta, Georgia

Mentor: Marc Huo, Stanford University

50 million global cases of Alzheimer's disease (AD) are exacerbated by the absence of treatment and progressive severity, necessitating proper early detection to medicate patients without significant neuronal degeneration. The proposed study thus aimed to determine features with which the accuracy of a more specified, multiclass classification of AD stages could increase, placing emphasis on extracting inter-cortical ratios in addition to conventional raw volumes as a mode of normalization. Acquisition of T1w MRIs from the OASIS-3 dataset was followed by image preprocessing, tissue classification, cortical segmentation, and volume extraction. Compiled volume and ratio features were fed into three multiclass classifiers: conventional volumes, proposed ratios, and combined features. Classification performance and feature importance measurements discerned classifier and feature significance. Metrics noted that implementing a combination of absolute volumes and inter-cortical ratios produced the greatest accuracy of the three algorithms. Within the combined classifier, more importance was given to specific ratios, namely CSF/WB and GM/WM, over absolute counterparts, indicating promising results for applying ratios as volumetric features to increase performance. The proposed algorithm achieved 81.03% accuracy, greater than current state-of-the-art approaches (limited to 50-70%) and for more classes, suggesting increased discriminative ability in identifying milder stages. The contributions of the study were twofold, indicating maximized performance with combined features and demonstrating greater precision of proposed ratios. Further study may include implementing sub-cortical structural elements and multimodal data to facilitate diverse data and higher multiclass accuracy.

Structural Deduction and Environmental Analysis of Novel Tirofiban and Coumarin Derivatives Originating from the Endophytic Isolate FM1005 (Xylaria sp.)

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Waiakea High School
Hilo, Hawaii

Teacher: Whitney Aragaki

Mentor: Dr. Shugeng Cao, Daniel K. Inouye College of Pharmacy, University of Hawaii at Hilo

This two-part analysis method (emphasizing environmental viability and novel compound deduction) is indicative of the viability of marine-based natural products to be used in pharmacology. Contextualization of environmental stressors on marine-based natural product sources containing high compound yields utilized data from NOAA Coral Reef Watch around the Papahānaumokuākea Marine National Monument. Innovation of an analysis and

comparison technique based upon previous data in regards to the prevalence of chemical moieties via statistical analysis and UV absorption utilized and placed in comparison to various published novel compounds derived via HPLC and NMR methods. Environmental risk analysis of bleaching episodes concluded that chronological progression correlates with increases in the time span of bleaching alerts, and the product viability analysis categorized calculations of effective isolation capabilities into six levels. The organism susceptibility ranking concluded that high-risk organisms fall within higher ranges of viability for usage in isolations and HPLC targeted research. Compounds 9 and 10 are classified as coumarin derivatives and possibly are the specific compounds within the strain FM1005 that previously exhibited antiproliferative action against prostate cancer cell lines. Compounds 1 and 2 showed similar antiplatelet activities to tirofiban due to their structural similarity and inhibition of the binding of fibrinogen to integrin IIb/IIIa. It was concluded that inhibition of glycoprotein IIb/IIIa by compounds 1 and 2 suggests the potential for mediating a thrombotic response, and are viable for further pharmaceutical-based studies due to a lack of an antiproliferative response against a non-cancerous cell line (HEK-293 Human Embryonic Kidney).

Epigenetic editing of Cdk5 leads to sexually dimorphic stress responses.

Mia Dittrich
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Armonk, New York

Mentors: Dr. Elizabeth Heller and Dr. Ajinkya Sase, University of Pennsylvania

Women are more prone to disorders such as PTSD and depression. Yet, most preclinical psychopathological research solely uses male subjects, and there is a paucity of sex-specific studies. Thus, I investigated sex-specific responses to chronic unpredictable mild stress (CUMS) and fear conditioning (FC). Additionally, I examined the role of epigenetic regulation of cyclin-dependent kinase 5 (Cdk5), implicated in stress, fear, and depression. Section one of this study used data pre-collected from mice exposed to CUMS or targeted epigenetic repression of *Cdk5* in the nucleus accumbens. I scored four tests modeling behaviors linked to stress disorders and measured Cdk5 protein levels. Results showed *Cdk5* repression decreased compulsive- and depressive-like behaviors in female, but not male, mice (compulsive: $p = 0.0177$; depressive: $p = 0.0027$), and anesthesia/surgery increased anxiety- and depressive-like behavior in male mice only (anxiety: $p < 0.0001$; depressive: $p = 0.0035$). These results suggest that targeted *Cdk5* repression has potential for female-specific therapeutics. Section two used data pre-collected from mice exposed to FC, with or without targeted epigenetic activation of *Cdk5* in the hippocampus. Results showed, during long-term fear retrieval, females, but not males, exhibited darting behavior—rapid locomotion in response to fear ($p = 0.0446$). Overall, this study elucidated sex-specific stress responses linked to epigenetic regulation and suggested *Cdk5* repression for potential female-specific therapeutics. Beyond the intricacies of Cdk5, this study shows disregarding sex in neuropsychiatric research is detrimental to understanding stress disorders. Thus, researchers must prioritize sex differences, laying the foundation for more effective and equitable treatments.

The Effect of Added Polyamines on *Glycine max* Responses to Drought

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Central Virginia Governor's School
Lynchburg, Virginia

Teacher: Dr. Michelle Douglass

The purpose of this research was to discover if added polyamines affected the growth rates and root-to-shoot ratios of droughted and nondroughted soybean plants. Soybean plants were given exogenously added polyamines and placed into drought conditions. The height of each plant was measured every two or three days, and the growth rate was calculated using the slope of the line of best fit for each plant's graphed measurements. After 14 days of growth, each plant's dry biomass was divided into 'roots' and 'shoots,' and the root mass of each plant was divided by its shoot mass to determine the root-to-shoot ratio. The experiment was conducted twice—once with a

moderate drought, and once with a severe drought. Two-way unbalanced ANOVA tests were run to determine significance. It was found that added polyamines had a positive significant effect on the root-to-shoot ratios of soybean plants in moderate drought conditions (*p-value* =.041), but not in severe drought conditions; however, drought had no effect on the root-to-shoot ratios in both moderate and severe droughts. This result did not support the research hypothesis that added polyamines would lower the root-to-shoot ratios of droughted plants. Alternately, both added polyamines and drought were found to have a significant effect on the growth rates of droughted plants in severe drought conditions. Polyamines had a significant effect on growth rates throughout the experiment (*p-value* =.007). This result did support the research hypothesis that added polyamines would increase the growth rates of soybean plants in drought.

Dragonflies Beat Infection! Fabrication of Antibacterial Nanostructures for Orthopedic Implants

Kara Fan (2nd place, Life Sciences)
Westview High School
San Diego, California

Teacher: David MacMartin

Mentor: Professor Albert Yee, Chemical and Biomolecular Engineering, University of California Irvine

Orthopaedic implants are highly susceptible to infection and development of biofilms.Almost one million cases of implant- related infections (IRIs) occur each year. Currently, antibacterial agents and chemical modifications are used to prevent biofilms, but these can run out over time. Instead of killing bacteria chemically, studies have explored alternative physical methods through contact killing.

The surface of dragonfly wings are covered in tiny nanopillars that have antibacterial properties. This study aims to biomimic the antibacterial nanostructures of dragonfly wings (Neurobasis chinensis) on Polymethyl methacrylate (PMMA) and with that, fabricate an antibacterial skull implant. To prepare a dragonfly wing replica, PDMS elastomer was used to create the mold by manually drop-casting the polymer onto the wing. Escherichia coli K12 was used to examine the antibacterial properties of the PMMA films. Two types of antibacterial property tests were performed. First, I measured the E. coli K12 growth on the PMMA film surface with and without nanostructures on Petri plates. This test assessed the growth of E.Coli bacteria on wings with around 87.5% growth inhibited. Second, I put the PMMA films in nutrient broth with E. coli and executed turbidity tests using a Spectrophotometer. The PMMA films with nanostructures were found to have a lower absorbance and a slower bacterial growth curve, indicating that it inhibited the bacterial growth.

I successfully biomimicked dragonfly wing antibacterial nanostructures that can be used for many applications. A potential cranial implant prototype was created.

An Analysis of the Association Between PM2.5 Exposure and COVID-19 Morbidity and Mortality

Hannah Gao
Harriton High School
Rosemont, Pennsylvania

Mentor: Dr. Jeffrey Field, University of Pennsylvania

The outbreak of COVID-19 has rapidly grown into a global health emergency and has negatively impacted the lives of billions of people. Despite the urgency of the situation, currently little is known about the factors that may

influence this disease. In particular, air pollution has been suspected to play a role in the transmission and prognosis of COVID-19. The purpose of this study was to explore the association between an air pollutant, namely PM2.5, and COVID-19 morbidity and mortality on the county level in Pennsylvania. This study utilized publicly available COVID-19 data and PM2.5 concentration data, and it employed log-linear regression models that adjusted for potential covariates relevant to the disease metric under analysis. Nursing home data was excluded from the total case and death counts in each county, since these congregate living facilities serve as hotspots for COVID-19 and may contribute to a false representation of the disease in the general population. The results showed a significant positive correlation between PM2.5 levels and both COVID-19 case counts and death counts after removing nursing homes. This work has important policy implications for disease prevention and the allocation of public health resources in areas with higher levels of PM2.5. These results also highlight the important role that environmental factors may play in epidemiology.

Computer User Interface Effect on User Attitude Towards Course Selection

Nathaniel Gao
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Sponsor: Sowmya Anjur

In order to investigate how a web page's user interface would affect the user's behavior and thought processes, a study was conducted in which high school students were given a self-coded web program with a list of courses to choose from. Students were split into three test groups: one was given control settings to sort the courses in various categories (difficulty, importance, etc.); the second was given false control settings that would randomly organize the courses; and the third did not receive any control settings. It was hypothesized that the presence of the control settings would increase the students' perceived control and push them to choose more challenging courses. To test this claim, the students' course selections were recorded and analyzed.

It was discovered that users who believed they had the ability to use the control settings to sort the course list to their own preference (groups 1 and 2) challenged themselves harder with their course selections. Many students in these groups reported that they utilized the control settings to select more stimulating and interesting classes. The data reflected that compared to the third group, they chose courses more essential to their goals as well as ones with higher difficulty. In conclusion the existence of the control settings, even when sorting by random, brought a sense of perceived control to the students and pushed them to select more challenging courses.

The Effect of Annealing on Cluster Formation

James Gonzalez (3rd Place, Physical Sciences)
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The creation of nanofilm (sheets of nanoclusters) are widely used in many materials today for structural engineering and electronic equipment. Manipulating and observing nanocluster growth in real life is costly and time consuming. The growth of clusters was studied using computer simulations to save time and resources. These programs incorporate four basic atomic processes and one after process: the deposition of adatoms (adsorbed atoms), diffusion, nucleation, growth of clusters, and thermal annealing. Annealing is the process of heating clusters of atoms to create a probability of atoms breaking off clusters. Annealing follows the rule of Ostwald Ripening, where smaller clusters are absorbed into larger clusters. Different temperatures and their roles have been identified. Furthermore, both size and spatial distributions of clusters before and after annealing were studied using histograms and pair-correlation functions, and the characteristic of the distributions were analyzed. Results found that higher annealing temperatures increased cluster density. Clusters were found to be much more compact

(little to no branching). The average distance between clusters increased. Comparison of simulation results with experimental scans support simulation validity. Potential applications of nano-engineering will also be discussed.

Mobile App Development to Treat Anxiety

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Radians School
Cayey, Puerto Rico

Mentor: Karina Martínez, Interamerican University of Puerto Rico

Since COVID-19 society is going through difficult times in which it becomes complicated to see family members, friends and go out since some places are restricted. Now of all times, anxiety within every human being grows because of not knowing what will happen later in the future. Young children are particularly affected in this pandemic since they may not know how to express to their caregivers how they feel or what they would like to do. The development of a mobile application to treat anxiety will help stimulate the brain through games, relaxing exercises, and symptoms logs. This will help induce the flow of oxygen, blood, and nutrients that will prevent the negative effects of anxiety. Mental health apps can be effective by making therapy more accessible, efficient, and portable. The app will be directed to children that are between 6 to 8 years old. By creating lists, a worry box, identifying feelings and motivate them to exercise can help the child to feel better and help them deal with anxiety. For this it is essential that they know how to identify how they feel that they listen to music and meditation to relax. Young children are very active and energetic human beings. Thereby, in the application there could be added video games, exercise, like yoga, and fun videos to maintain the children's lively feeling. It is of the utmost importance that children can take some time out to relax and reflect on their daily lives.

Modeling the Effects of Social Isolation on Serotonergic Neurons by Upregulating Calcium-Activated Potassium Channels

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With the recent quarantine (2020) caused by the novel coronavirus pandemic, social isolation stress (SIS) has been significantly affecting a large number of individuals, leading to depression-related symptoms and disorders (Peng et al., 2020). The monoamine hypothesis predicts that the underlying pathophysiologic basis of depression is a depletion in the levels of certain neurotransmitters, including serotonin (5-HT), in the central nervous system. Most of the 5-HT is produced in the dorsal raphe nucleus (DRN), and it is known that SIS causes the firing rate of serotonergic neurons to decrease through the upregulation of calcium-dependent potassium channels (Jesulola et al., 2018). To model the effects of 5-HT regulation seen in animal trials of SIS, we modified a computational model of a dopamine neuron in the DRN to include Ca2+ activated SK channels that are expressed in 5-HT neurons. The model's behavior was then validated with vitro neurophysiological data. SIS influence on the excitability of 5-HT neurons was simulated by increasing SK3 channel concentration, as well as Ca2+ ion currents. The computational model suggests a link between the downregulation of SK3 channels and increased 5-HT neural activity, suggesting a

potential treatment for depression caused by SIS and other mood disorders. Current treatment options for depressive disorder include selective serotonin reuptake inhibitors (SSRIs) which may not be entirely effective in individuals under SIS conditions. Our current study proposes the use of calcium-activated SK channels as a new therapeutic target for depressive and mood disorders.

ALVIN: An Intelligent Stereoscopic Olfactory System for Autonomous Localization of Volatile Organic Compounds
Audrey Gruian (1st place, Engineering & Technology)
Eastlake High School
Sammamish, Washington

Teacher: Casey Green

Electronic noses, or e-noses, are still a very new concept in modern research; and while few working prototypes exist, the implications of such devices are vast. Harnessing odor-tracking technologies could lead to increased food safety, workplace safety, and even early disease detection. In this study, we focused on the detection of airborne VOCs. The purpose of this study was to design, build, and test a proof-of-concept, bio-inspired odor localizing robot to track and locate the source of an airborne odor. Inspired by the functionality of a dog's nose as well as the odor tracking capabilities of lobsters and moths, the project was carried out in three sections: designing and building a robot base with a stereo-olfactory system, calibrating the olfactory system sensors to utilize normalized sensor readings, and creating a unique odor localizing algorithm to allow for autonomous localization of an odor source. ALV+IN, or the Autonomous Localization Vehicle with an Intelligent Nose, utilizes previous normalized sensor readings to determine a path of travel through a butane plume to its source. Though ALV+IN can successfully locate odors as they move with the robot, this study was limited by safety constraints. This was due to the feasibility of simulating large-scale odor plumes to produce fully autonomous results. In a real-world implementation, such a device could greatly improve efforts in detecting hazardous gas leaks and assist in natural disaster recovery efforts.

Predicting Harmful Algal Blooms in Green Valley Lake
Claire Gu
Valley High School
West Des Moines, Iowa

Teacher: Karen Downing

Cyanobacteria, or blue-green algae, are photosynthetic aquatic organisms that produce toxins. They can grow excessively to form large-scale blooms under favorable environmental conditions. These harmful algal blooms, known as CyanoHABs, can pose serious threats to human and animal health and aquatic ecosystems. In Iowa, lakes are susceptible to CyanoHABs due to excess nutrient runoffs from farm fields. Recently, CyanoHABs have been on the rise, but little research has been done to create models to predict CyanoHABs occurrences. The goal of this study was to develop a deep neural network (DNN) machine learning model to predict microcystin (a type of cyanobacterial toxin) and chlorophyll-a concentrations, two key indicators of CyanoHABs, using physiochemical water monitoring data collected from Green Valley Lake. The DNN model predicted results more accurately based on two error metrics than the traditional linear regression model developed for benchmarking. The study also identified nutrient conditions and seasonality as the two environmental variables that contributed most to CyanoHABs. Overall, the DNN model yielded good results using eight years of monitoring data. When more data becomes available in the future, this model can be used to effectively predict CyanoHABs occurrences in Iowa lakes to reduce the risk posed by them.

In Silico Mapping of 14-3-3ζ and TRAF Protein Interactions
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Sylvania Northview High School

Sylvania, Ohio

Teacher: Kathryn Nelson

Research Advisor: Dr. Ritu Chakravarti, Department of Physiology and Pharmacology, University of Toledo

Recent advances show that the 14-3-3ζ protein participates in several immune regulations and is a unique regulator of IL-17A signal transduction. The IL-17A signal transduction triggers two, 14-3-3ζ-TRAF6 and 14-3-3ζ-TRAF5-dependent intracellular pathways responsible for IL-6/IL-8 and CXCL-1, respectively. Improved IL-17A signaling blockers are desirable in treating inflammatory diseases. Due to its unique role 14-3-3ζ is an attractive target to regulate IL-6 and CXCL-1 levels. The aim of this study is to determine interaction sites between 14-3-3ζ and the TRAF (5 and 6) proteins utilizing bioinformatic analysis. Using ZDOCK, I examined the putative site of the 14-3-3ζ interactions on TRAF (5 and 6) with or without any restrictions. The mapped interacting residues were mutated, and an effect on the interaction with 14-3-3ζ was observed. To further evaluate the interaction quality, Prodigy was utilized to measure binding energy for several possible structures and narrow down the selected interaction sites further. The results indicate that site 479-485 is the putative target of the 14-3-3ζ-TRAF5 complex with ΔG of -17.5 kcal/mol and Kd of $1.60x10^{-13}$ M. The results for the TRAF6 experiment indicate that residues 483-488 interact with 14-3-3ζ with ΔG of -19.1 kcal/mol and a Kd of $9.50x10^{-15}$ M. These results identify the binding sites between 14-3-3ζ and TRAF (5 and 6) and provide a rationale to investigate the 14-3-3ζ and TRAF proteins further for the development of a future therapy. This therapy would have applicability to autoimmune disease, chronic inflammatory disease, and Coronavirus Disease 2019.

Solving the Issue of Inefficiency for Multiple Faceted Variable Energy Systems

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Teacher: Reginald Tyler

This is the third iteration of a research and development project to improve a variable energy system. The system is composed of a commercial grade vertical axis wind turbine (VAWT) blade with embedded solar cells to generate supplemental electricity. Digital models were developed to engineer and design a 3D printed wind turbine blade. Then concepts from physics were applied to solve problems for output efficiency. A major disadvantage of conventional wind turbines is intermittency and failure to produce electricity when the wind resource is compromised. This study provides an innovative approach that combines twin technologies to overcome inefficient and variable renewable energy systems. The material properties of the turbine's blades can be adjusted such that the system is economically viable through the end of life. Secondly, another embedded resource with storage capacity can address the intermittency. The researcher for this project has applied for and received a provisional patent to advance this technology. This year a utility patent was filed which demonstrates that the standards have been met to satisfy legal requirements to move toward commercialization.

Shockwave Induced Droplet Breakup
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Mentor: Dr. Shyam K. Menon, Department of Mechanical Engineering, Louisiana State University

A shockwave is essentially a traveling wave moving at supersonic speeds generating a step change in fluid properties such as pressure and velocity across the wave. There are several engineering applications and naturally occurring phenomena where a shock wave interacts with liquid droplets. Relevant examples from engineering include aircraft flying at high speeds through rain, or fuel droplets present in rocket engine combustion chambers. In nature, volcanic eruptions are accompanied by shockwaves, which can interact with molten magma. The interaction of a shock wave with liquid droplet results in the breakup of the droplet leading to formation of ligaments and smaller droplets, and liquid evaporation and combustion under the appropriate conditions. The underlying physical processes in the droplet breakup process are not well understood. Computational Fluid Dynamics (CFD) is a tool that can be used to analyze the fluid dynamic processes that occur over a range of length and timescales during the shockwave–induced droplet breakup process. The goal of this work is to use CFD implemented using Ansys FLUENT software to study the interaction of a shockwave with a single droplet. The breakup process will be studied as a function of shock strength and fluid droplet properties such as density and viscosity. Droplet breakup time will be estimated using the simulation results and correlated to shock parameters and fluid physical properties. Longer term, this work will consider fuel droplets in an oxidizing environment and use CFD simulations to characterize ignition and combustion processes resulting from shockwave-induced droplet breakup.

Faster Drying in Nail Polish: What is the Best Method?
Allison Havard
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DoDEA Sigonella, Sicily

Teacher: Marsha McCauley

Although painting beautiful colors on fingernails is enjoyable, it can be far too tedious to wait for the polish to dry fully. A solution to this is testing different methods of drying nail polish to see which one works most efficiently to dry the polish faster than normal. The goal was to find a convenient way to cut down the amount of time spent being extra cautious, waiting for the polish to dry. It was hypothesized that if different methods of drying nail polish faster than normal are tested, then the baking spray method will cause the biggest decrease in drying time. The overall result of the experiment was that the homemade solution caused the biggest decrease in drying time, becoming the best method tested by half the amount of time of the second-fastest method. This homemade solution is a gateway to the engineering of a nail polish that dries “instantly.”

Prediction of Molecular Energy Using Coulomb Matrix and Graph Neural Network
Rishi Hazra
Skyline High School
Sammamish, Washington

Mentor: Prasenjit Hazra

The molecular energy tells us which isomers are favored at equilibrium, and how fast each reaction will take. It is also useful in understanding biological pathways in cell functions that can guide us towards drug discovery. The standard enthalpy of formation can be measured directly from the chemical reaction or indirectly with the application of Hess’s law. However, both of these require the chemical reaction as well as the measurement of heat (using calorimetry). These methods for determining the molecular properties of new and large compounds- which are essential in drug manufacturing- are time consuming and expensive. Molecular energy has also been investigated computationally. There are several methods in use: 1) Ab Initio Calculations; 2) Semi-Empirical Calculations; and 3) Density Functional Theory (DFT). Nevertheless, these calculations are slow and demand the

use of limited computer resources (memory and disk space). The purpose of this project is to apply machine-learning techniques to create a model through data constructed from known molecular properties. Once the model is created, the molecular properties (e.g., molecular energy) of new molecules can be predicted quickly. The models in this experiment are based on two popular theories: The Valence Bond Theory and The Molecular Orbital Theory. Two different machine-learning techniques will be used to create models based on the two theories and the prediction results will be compared statistically. These models can be used in computational design and will aid in the discovery of new molecules, compounds, and drugs.

Effect of Bacteria and Fungal Interactions on Mosquito Egg Hatching

Jadyn Henry
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Augusta, Illinois

Sponsors: Sue Henry and Kassie Henry

Mosquitoes represent a significant proportion of insect biodiversity, and yeasts fill important roles in food webs, decomposition of organic matter, and nutrient cycling in aquatic ecosystems, but potential mosquito-fungal interactions remain largely unknown. The purpose of this scientific investigation was to evaluate the potential differences of bacteria within red and white Meyerozyma yeast isolates. It was observed that agar plates with Meyerozyma yeast and different antibiotics affected the pigment of the samples. The Meyerozyma red and white yeast samples went through DNA extraction and PCR, and samples were sent to a commercial lab for next generation Illumina sequencing. After analyzing 133,127 sequences obtained from six isolates of Meyerozyma red and white, it was determined that the bacterial communities within Meyerozyma-red and white were abundant and diverse, with eleven genera identified. The most abundant bacteria found within the Meyerozyma-red isolates was Serratia (88.87%), and the most abundant bacteria found within the Meyerozyma-white isolates was Sphingobacterium (87.38%). These bacteria can affect the morphology of the yeasts, in this case causing the red pigment of Meyerozyma red. Additional research on Serratia is needed in order to fully understand its impact on mosquito-fungal interactions.

The Role of the Phytotoxic Flavone Apigenin in the Allelopathic Pathway of the Invasive Plant Species, *Lonicera maackii*

Maya Irvine
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Camdenton, Missouri

Mentor: Christopher Reeves, Camdenton High School Science Research Program

Lonicera maackii is a Eurasian invasive plant species found across much of North America that is hypothesized to have allelopathic and phytotoxic effects towards herbaceous plant species. Few studies have been conducted relating to the allelopathic effects of *L. maackii* in an ecological perspective, so the intention of this study is to provide further ecological context. Apigenin is a flavone that was discovered in the leaves of *L. maackii*, along with its glucoside derivative, apigenin-7-glucoside, and has shown to inhibit the germination of *Arabidopsis thaliana* seeds. This study explores the effects of apigenin as a possible allelochemical in soils in which *L. maackii* has infested, as well as laboratory studies testing the effects of lowered pH levels and the varying concentrations of *L. maackii* leaf litter on the germination rate of *A. thaliana* seeds. Germination studies confirmed that aqueous extracts of *L. maackii* dried leaf litter inhibit *A. thaliana* seed germination, significantly dependent on

concentration. Aqueous *L. maackii* solutions with a pH of 5.0 had little effect on the germination rate of *A. thaliana* seeds.

My Skin: A Deep Convolutional Neural Model for Skin Cancer Identification with Coarse-to-Fine Contextual Memory (CFCM)

Ameya Jadhav
Denmark High School
Alpharetta, Georgia

Teacher: Shelby Cochran

Skin cancer, the most common human malignancy, is diagnosed visually, beginning with an initial clinical screening and followed with a dermoscopic analysis, a biopsy and histopathological examination. An intelligent, accurate automation of skin lesion identification and classification is a challenging task, mainly because of the fine-grained variability in the appearance of skin lesions. Deep convolutional neural networks (CNNs) show high potential for general and highly variable tasks across many fine-grained object categories. This project utilizes deep CNNs, trained end-to-end from images and disease labels as inputs. The CNN is trained on 10,682 clinical images. Its performance has been tested against an additional 3,561 clinical test images and an even further 3,562 clinical validation images for two critical binary classification use cases: melanoma, or not melanoma (identification of the deadliest skin cancer). This project explores various machine learning models and training hyperparameters, finetuned to achieve the highest binary validation accuracy. Further, Coarse-to-Fine Contextual Memory (CFCM) has been used for deep encoder-decoder architecture clinical image segmentation to improve overall performance. Various other high utility machine learning algorithms and methods have been used, including data pipelines, unique image augmentation, and transfer learning. The project achieves performance on par with board-certified dermatologists (92.7%), demonstrating an artificial intelligence capable of classifying skin cancer with a level of competence comparable to dermatologists. This project also covers a developed iOS app, named My Skin, to distribute the use of the artificial intelligence (among other features), and can therefore potentially provide low-cost universal access to vital diagnostic care.

Using Data Science to Explore Historical Trends and Predict Future Rates of COVID-19 Infections

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Oak Ridge, Tennessee

Mentor: Dr. Chad Steed

Despite widespread knowledge that COVID-19 is spread through close contact, such as large group gatherings and confined spaces, people continue to treat holidays as an excuse to escape lockdown restrictions and visit with people outside of their households.

To better understand how these holiday gatherings affected general case trends of COVID-19, I used data science methods to characterize the data and explore it, then used algorithms to predict future infection rates. Additionally, I examined current and future hot spots. The cases of COVID-19 were counted using the data provided by Johns Hopkins University of Medicine. The prediction was that certain major events or holidays would cause significant spikes in the general rise of cases.

Using regression analysis, a function was created to predict case counts with a minimum amount of error as compared to the actual case count. Regression analysis was the best tool to use because it efficiently minimizes human error.

The significant events are easily seen through the different visualizations of the data. The function was trained until the level of error had reached a sufficient minimum, then was used to predict additional spikes in number of cases. The results support the theory that major holidays have a significant impact on trends in case counts.

Molecular Dynamics Simulation of Novel *Klebsiella pneumoniae* Treatment Disrupting the Outer Membrane

Eleanor Jung
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San Diego, California

Teacher: Amy Klingborg

Klebsiella pneumoniae exhibits among the highest rates of antibiotic resistance and is currently the main cause of carbapenem resistant infections, yet there are no clinically effective treatments available for many who contract the Gram-negative bacterium. Artilysins, proteins each composed of an endolysin and a lipopolysaccharide (LPS) degrading peptide fused together, are a possible alternative to antibiotics for Gram-negative bacterial infections. In an earlier phase of this project, an Artilysin to target *K. pneumoniae* was designed and a model was created of its endolysin portion. In the current stage of this project, a computational model of the rest of the Artilysin is created, validated, and used to demonstrate stability in water at body temperature. Because fusing domains can bring about unforeseen changes to protein behavior, molecular dynamics is used to provide insight to mechanisms at the molecular level. However, with accuracy, size, and simulation time comes an increasingly expensive computational cost. To evaluate the efficacy of the designed Artilysin before investing a large amount of resources, the Artilysin is simulated above a model of an outer membrane resembling that of *K. pneumoniae* for 2 microseconds at body temperature. This is compared against two controls, one with the endolysin above the outer membrane and the other with only the outer membrane. Compared to the endolysin, the Artilysin is shown to disrupt membrane density deeper into the bilayer. Further investigation reveals changes in specific bonds in the LPS backbone and carbon tails that accompany the density changes.

Novel miRNA and gene enrichment associated with cardiac function in athletes

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Johnston High School
Johnston, Iowa

Teacher: Sara Kate Howe

Mentors: Dr. Randolph S. Faustino, Sanford Research and University of South Dakota School of Medicine
Dr. Claudia C. Preston, Faustino Lab, Sanford Research

Cardiovascular disease is the leading cause of death in the United States, and one of the most well-known preventative measures is exercise. Paradoxically, athletes still experience abnormal cardiac function, with some cases resulting in heart failure and death each year. Exercise training is linked to circulating microRNAs (miRNAs) that have been associated with cardiac, including cardiac hypertrophy, myopathy, morphogenesis, and calcium signaling/handling. This study aims to identify potential circulating miRNA biomarkers to aid diagnosis and the development of therapies with the goal of mitigating cardiac pathologies in athletes. After performing an integrative bioinformatic enrichment analysis of publicly available datasets, consisting of athletes' gene and miRNA expression pre- and post-exercise training, six genes and six miRNAs were identified to be common between two or more datasets and analyzed to have cardiac-specific function. The enrichment of peripheral miRNAs associated

with cardiac function after exercise training provides insight into potential cardiac stress-induced miRNA expression changes. Similar patterns of up- or down-regulation of enriched post-training miRNAs between pleiotropic cardiac pathways can reveal significant miRNAs that affect the cardiac function of athletes.

Exploring the Use of Carbon Nanotubes to Develop Breath Biomarkers
Shriya Kapoor
Spring Valley High School
Columbia, South Carolina, USA

Teacher: Lindsey Rega

Common pulmonary diagnostic tests, although inefficient, expensive, and labored, have remained unchanged for several years. Developing an all-in-one sensor-based technology to detect the organic composition of exhaled breath can serve as a biomarker for prediction and early diagnosis of pulmonary diseases. Carbon nanotubes (CNT's), used for their thermal and electrical properties, were hypothesized to be used as a thermistor and humidity sensor for a) understanding the responsiveness of sensors toward the breathing cycle of each subject and b) evaluating characteristics of inhaled and exhaled breath temperature and relative humidity, including peak to valley values, amplitude, and frequency. A LabVIEW data acquisition system (DAQ) was developed for an Arduino microcontroller. Using three pairs of CNT sensors, tests were performed to analyze the breathing pattern of two participants under two physiological conditions. The first part of the study validated that the sensors were able to accurately detect the components of the breathing cycle (e.g., inhalation, exhalation, and pause). For all three pairs of sensors there was statistically no significant difference in the temperature frequency (breaths per minute) $F(2,54) = 0.26$, $p > 0.05$ for 1st participant and $F(2,54) = 0.01$, $p > 0.05$ for 2nd participant's breathing patterns. Lastly, after physical exercise, each participant's increased breath rate with increased heart rate was significantly different from the normal breath rate. As a next step, signals from the humidity sensor and a possible correlation between amplitude and frequency to the volumetric characteristics of the breathing cycle will be developed.

CropMates: A low-cost and efficient IoT and Al- based integrated system for the detection and treatment of crop diseases and deficiencies that maximize the quality and quantity of crops to potentially eradicate world hunger
Shraman Kar
duPont Manual High School
Louisville, Kentucky

Teacher: Valerie Conti

The world population is expected to increase by 2 billion by 2050. A person dies of hunger every 3.6 seconds. The UN has come up with a list of 17 goals to make the world a better place and ending hunger comes at second. A 119% increase in yield is required by 2050 to sustain life. As the amount of land cannot be increased, the only way is by increasing crop yield from the same land. Research has shown that disease and nutrient deficiency related yield losses have cost the world 60% of global agricultural productivity. Diagnosis of the disease and nutrient deficiency in a large farm is very difficult because of the number of crops. This project, "CropMates", aims to identify crop diseases in a vast area of farmland by first surveying the acreage using a GPS enabled drone. The camera fitted drone captures video and pictures of the farm while flying over the field. A deep learning algorithm is created to identify leaves from these pictures. Another deep learning-based algorithm using AlexNet architecture is trained with 38 different classes of diseases on 87,000 images of leaves to identify a disease from these leaves. An Artificial Neural Network is developed and is trained on 20,000 data points to identify nutrient deficiencies in the soil from IoT enabled sensors to put across the farm. An app is built to show the results and to recommend the type and amount of pesticide and fertilizer for optimum crop yield.

Arctic Methane Risk: Remote sensing and quantifying permafrost melt in circumpolar regions by performing fractal analysis to establish temperature correlations

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Teacher: Dr. Lara Shamieh

An estimated 1.5 trillion tons of methane (CH_4) and carbon dioxide (CO_2) are trapped underneath permafrost. The effective large-scale quantification of permafrost degradation is critical to characterizing permafrost melt risk; however, only 150 permafrost locations are currently monitored, and they depend on direct field measurements. Thawing permafrost create thermokarsts that contribute to surface fracture. This study investigated the potential of using fractal analysis on Landsat images to quantify the surface complexity of the images, and rapidly characterize and identify permafrost regions undergoing critical melting. Data and remote-sensed images from the Anaktuvuk river tundra fire of 2007 were used to calculate fractal dimensions and establish baselines for critical melting. The study then evaluated fractal dimensions of annual Landsat pictures of permafrost regions (n = 62), compared them against baselines for critical melting, and performed linear regressions against the regions' average annual thaw temperature. The results showed that critical permafrost degradation results in the regions' fractal dimension changing by -0.094 to -0.203 in magnitude, and that fractal dimension correlates inversely with average thaw temperature (p-value = 0.006). The results further identify three regions (Cocker Gap Lake, Claudi Lake, and Nerka Lake) in Alaska as undergoing critical permafrost degradation. An independent analysis by Anthony, et al. (2016) in *Nature Geoscience* provides confirmatory evidence of permafrost degradation in the Cocker Gap and Claudi lakes. The results reveal that surface fracture determined from remote-sensed image analysis is a potential indicator of permafrost degradation. This approach presents the prospect to perform large scale permafrost monitoring.

Dendrochronological Data Analysis to Measure Climate Sensitivity and to Develop Climate Reconstructions

Shreya Khullar
West Senior High School
Iowa City, Iowa

Teacher: Carolyn Walling

Dendrochronology is a scientific field that uses the annual growth rings on trees to find out the exact year the tree was formed, helping scientists date events and map environmental change. The thickness of each ring can be used to study fluctuations in temperature and precipitation, since optimal conditions for the particular species (in this study, White Oak), will result in more growth, and thus thicker rings for a given year. Understanding past climate helps us to explain how current ecosystems came to be, and how environmental conditions may change in the future. Reconstructions of past climate conditions are attained from paleoclimatology proxies. These include vegetation, ice cores, and temperature, but I observe tree ring growth indexes (trsgi) in relationship to precipitation (ppt). This relationship is explored by graphing data values to see the correlation between precipitation in different seasons and growth (testing climate sensitivity). Using these results, I am able to make climate reconstructions and predict precipitation values back to the 1600s, as well as extrapolate data forward in time to anticipate tree growth into the future, thereby expanding scientific knowledge on paleoclimates as well as improving the accuracy of future climate predictions and how these conditions affect crop yields.

The Energy Production of Biodiesels Sourced from Canola Oil, Used Vegetable Oil, and Tallow, as Compared to Petroleum-based Diesel Fuel

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DoDEA Camp Humphreys, Republic of Korea

Mentor: Scott Bittner

In the age of global warming and climate change, the need for efficient and clean energy sources has never been more important. Biodiesels, which are a type of diesel derived from biodegradable sources, are much more environmentally-sustainable when compared to diesels of fossil fuels. Since biofuels are such a promising alternative to petroleum-based fuels, it is hypothesized that if lamps fueled by biodiesels made from canola oil, used vegetable oil, and tallow are lit, the canola-based biodiesel would produce the most energy per gram of fuel. To test this hypothesis a calorimetry test was conducted for each of the types of biodiesel, plus one for a petroleum-diesel lamp as the control. The results showed that for one gram of fuel, the petroleum diesel produced the most energy, followed by vegetable oil biodiesel, tallow biodiesel, and then canola oil biodiesel. These results refute the hypothesis, showing that canola oil biodiesel actually is the least energy efficient among the other fuels. Due to such a large difference in values between the petrodiesel and biodiesel, it became clear that homemade biodiesel was not comparable to the store-bought petroleum since there were many factors that could influence the production of biodiesel.

Analyzing Disparities of Eviction During the COVID-19 Pandemic Through Spatial Statistical Analysis

Eyrin Kim (2nd place, Medicine & Health/Behavioral Sciences)
Farragut High School
Knoxville, Tennessee

Mentor: Dr. Hyun Kim, University of Tennessee, Knoxville

An unprecedented rise in eviction cases across the United States during the COVID-19 pandemic has underscored clear disparities between evictees of differing groups (in particular, races). In order to determine the variance of eviction-related disparities by region, eviction and pandemic data of New York, NY; Memphis, TN; and Fort Worth, TX (cities with over 10,000 evictions since March of 2020) was analyzed by a sequence of analysis. This sequence included longitudinal visual inspection, ANOVA, and the Exploratory Regression Model (ERM) for variables in demographic, socio-economic, and housing environment related categories. Results demonstrate that eviction-related disparities vary by city (ANOVA, $p < 0.01$), even with homogenous efforts to mitigate such disparities during the pandemic. Further, the ERM identified the best-fit multi-regression model for eviction in each city out of a total 760 possible models, based on a combination of input variables. Specifically, four critical explanatory variables were specified in each of the three cities, with the total number of households, poverty level, and multiple race-associated variables being common to more than one city. The selected key variables demonstrate statistically significant explaining power over eviction-related disparities in their respective cities. Results highlight that although current policy such as the federal moratorium has been effective in curbing the growth of eviction rates, future intervention should be tailored to specific regions given the revealed conditions of their intrinsic disparities.

Save Our Sons: Exploring RNAi-mediated Intragenomic Conflict in *D. sim* through Genetic Assays and Testis Cytology

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Hunter College High School
New York City, New York

Teacher: Philip Frankel

Mentor: Jeffrey Vedanayagam and Chun-ming Lai, Memorial Sloan Kettering Cancer Center

Intragenomic conflict occurs when selfish genes attempt to increase their own prospects of replication at the expense of the organism. It has clinical and ecological significance–the genes and pathways involved are often co-opted by lineages of cancer cells, and intragenomic conflict itself can have impacts on genome evolution, sex determination, and speciation. One of the most studied cases of intragenomic conflict is the Durham and Winters sex-ratio (SR) meiotic drive systems in *D. simulans* (*D. sim)*. Both systems consist of distorter and repressor elements that bias and restore equal transmission of X and Y sperm, respectively. However, mechanisms of SR meiotic drive systems are still poorly understood, and there exist little genetic evidence of the active outputs of the distorters *MDox* and *Dox* and repressors *Tmy* and *Nmy*. This study elucidates genetic evidence for the SR-distorting activities of *Dox* and *MDox* and the SR-restoring activities of *Tmy* and *Nmy* through genetic sex-ratio assays of CRISPR null mutants. An examination of the interactions between *Tmy* and *Nmy* also showed that the Winters and Durham systems may overlap and have synergistic effects. Moreover, through immunostaining and testis cytology assays, it was found that the etiology of *Dox* and *MDox*-induced SR bias lie in abnormal spermiogenesis. Altogether, the data from the study demonstrates an unanticipated complexity of SR distorting loci in *D. sim,* provides evidence that continuous cycles of sex ratio distortion and suppression mediate balanced sex ratio, and discusses the first case of two intragenomic conflict systems that present synergistic interactions.

Designing a Monte Carlo Python Computer Program to Model Random Mutations Across T-cell resistant Sequences and Hotspots in the SARS-CoV-2 Spike Glycoprotein

Aditya Koushik (3rd place, Biomedical Sciences)
La Cueva High School
Albuquerque, New Mexico

Sponsor: Kiran Bhaskar

COVID-19 has killed over 2.5 million people worldwide and has infected more than 114 million – making it one of the most devastating pandemics in recent history. The purpose of this project is to use Monte Carlo simulations in the Python programming software to predict and model sporadic mutations in T-cell resistant sequences and hotspots in the SARS-CoV-2 spike glycoprotein. First, the Immune Epitope Database (IEDB) library was used to acquire 48 well-validated T-cell epitopes in the SARS-CoV-2 spike protein. Using Monte Carlo simulations in Python (MC-P), the number of random mutations needed to change a 9-mer T-cell resistant sequence into a T-cell epitope was recorded. Next, in a separate MC-P model, the number of cycles required to randomly replace a single amino acid in the 9-mer stretch of spike protein to a new highly transmissible variant of SARS-CoV-2 (D614G, V483A, G4765, and L54F) was recorded. My results show that; 1) Randomly altering amino acids in the 9-mer T-cell resistant sequence (“VLYQDVNCT”) for 10,000,000 cycles did not match any of the 48 T-cell epitopes. 2) Simulation of single point mutations (D614G, V483A, G4765, and L54F) took an average of 6-7 randomization cycles (much more frequent than conversion into a T-cell epitope) when ran through the program. Together, these results suggest that the conversion of a T-cell resistant sequence into a T-cell epitope is rare in the SARS-CoV-2 spike protein, and single point mutations in spike protein are more frequent, which could result in new highly transmissible variants of the virus.

Using *Drosophila melanogaster* to Elucidate Sleep and Circadian Rhythm Disruptions after Traumatic Brain Injury (TBI)

Shan Lateef (3rd place, Medicine & Health/Behavioral Sciences)

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Supervising Scientist: Jennifer James, Thomas Jefferson High School for Science and Technology

Traumatic brain injury (TBI) is a leading international cause of morbidity and mortality and can significantly disrupt sleep-wake physiology by poorly understood mechanisms. The goals were to utilize Drosophila melanogaster as an animal model of single and recurrent TBI and: 1) Determine whether total amount and distribution of sleep is significantly altered. 2) To assess disruptions in circadian rhythm by measuring circadian period (τ) and rhythmicity index (RI). 3) To study whether therapeutic hypothermia can minimize disruptions in circadian rhythms and sleep. Methods: A "high-impact trauma" (HIT) device was built, causing mechanical damage to the brain. Sleep and circadian data was obtained by monitoring fly locomotor activity with the Drosophila Activity Monitoring (DAM) system. Male and female data were independently analyzed due to known sexual dimorphism of sleep architecture. Results: Following single and rTBI, female flies demonstrated increased daytime somnolence while males subjected to rTBI had decreased night sleep amounts. Therapeutic hypothermia did not mitigate the symptoms associated with sleep-wake cycle disturbances in females after TBI, however, cooling did increase the amount of night sleep in male flies subsequent to rTBI. The circadian rhythm appeared more resilient to disruption after TBI, but we did observe increased numbers of arrhythmic flies, particularly among the female cohort, after TBI. **Conclusion:** 1) Recurrent TBI in flies shows altered sleep patterns and disrupted circadian rhythms, with distinct sex differences. Thus, male and female brains may respond differentially to TBI and this must be considered while addressing their disrupted sleep and circadian physiology.

Correlation Analysis of CAFO Density and COVID-19 Exacerbations in North Carolina Zip Codes

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Langhorne, Pennsylvania

Research Advisor: Dr. Jeffrey Field, University of Pennsylvania

CAFOS (centralized animal feeding operations) have been documented to have adverse effects on public health of surrounding communities. Due to the release of respiratory irritants from CAFOS such as PM 2.5, ammonia, and sulfur dioxide it has been shown that repeated exposure to CAFOS increases the likelihood of respiratory diseases such as asthma and bronchitis. With the ongoing COVID-19 pandemic, of which a large risk factor for severe symptoms is asthma, we investigated whether there is an increased mortality rate, and cases per 10,000 in zip codes in North Carolina associated with a large density of CAFOS. Our results found there was a Spearman correlation coefficient of 0.27 (weak statistical correlation) for cases per 10,000 and a coefficient of 0.18 (no statistical correlation) for mortality rate. We speculate that CAFO proximity is not impactful enough to cause increased death rate but could aggravate symptoms.

Degradation of Surface Textures of 3D Printed Alginate Scaffolds for Bone Implants

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Mentor: Brian Beatty, PhD, New York Institute of Technology

3D printed methacrylated alginate scaffolds are among the most cutting-edge of technologies being developed for helping bones heal from injury or surgical interventions. These materials are essentially gelatins printed in a grid of fine filaments with pores designed to optimize bone growth, and the maintenance of surface texture is important for success. Little has been done to characterize the surface texture of these materials besides SEM, so a white light reflectance confocal microscope was used to examine the surface roughness quantitatively. Four scaffolds with

nano-silicate additives were scanned with a Sensofar S Neox confocal microscope using the 50x objective with green light and a fusion of confocal and focus variation methods to maximize scan quality. Scans were done every 10-15 minutes with a freshly printed scaffold and then of previously frozen scaffolds on Day 1, 2, 7 and 84 after removal from the freezer to measure the initial and long term degradation rate at refrigerated temperatures. In total, 29 ISO-25178 areal roughness parameters, 3 motifs analysis parameters, and 4 texture direction parameters were tested with linear regression and a one-way ANOVA and Tukey's post-hoc test. Most changes occurred between the Fresh cohort and subsequent days of scans after frozen specimens thawed. These changes resemble what is expected when a cylindrical surface dries and wrinkles, leaving elevated peaks and valleys and irregular creases and wrinkles. This change is likely due to drying out or freezing damage, and suggests that alginate scaffold materials change surface metrology features dramatically through time after printing.

Detecting Differential Transcription Factor Binding Using Single-Cell DNA Accessibility

John Lin (3rd place, Life Sciences)
Boston Latin School
Boston, Massachusetts

Teacher: Kathleen Bateman

Mentor: Dr. Thouis (Ray) Jones, Broad Institute

Common genetic diseases—systemic diseases caused by thousands of mutations—affect millions of people around the world. Many of these mutations fall within regulatory regions. While the mutations associated with these diseases are widely known, the link between these mutations and their role in disease pathogenicity has largely gone undiscovered, serving as the premise for this project.

Single-cell ATAC sequencing, which examines cells at individual levels (rather than in bulk), provides a venue in understanding the biological effect of mutations on cells. This study aims to harness this novel technology to distinguish bound and unbound transcription factors, which play a pivotal role in gene expression. We hypothesized that bound transcription factors would have fewer sequencing "cuts" or fragments cleaved by the sequencing enzyme.

Using data from CD8+ T-cells, relevant transcription factors were identified based on enrichment. Expected and observed cuts were computed for each relevant transcription factor site. Potential bound and unbound sequencing sites were identified after calculating significance between the observed and expected. Finally, a base-by-base metaplot was developed for bound and unbound transcription factor sites to examine differences between the two.

In the end, the study finds that regions with lower observed cuts than expected cuts conferred protection from sequencing enzymes, indicating the presence of a bound transcription factor. In distinguishing between bound and unbound transcription factors, the study paves the way for using single cell ATAC-seq to understand the biochemical mechanism underlying common diseases by identifying the cell types and changes in transcription factor binding caused by genetic diseases.

A Bacterial Isolate Inhibitory to Growth of Foodborne Pathogen Listeria

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Bacteriocins are proteins produced by bacteria to inhibit growth of other microorganisms. During research, we found that some bacterial colonies with similar morphology to Listeria were remarkably effective at inhibiting the growth of *L. monocytogenes*. One of the colonies was isolated and named AR-1. Antibacterial spectrum testing indicated that AR-1 is inhibitory to only Listeria growth. A co-culture assay demonstrated that AR-1 can inhibit growth of Listeria *monocytogenes* at various ratios, and when AR-1 is applied at a 10^4 to 1 ratio to *L.monocytogenes,* growth of *Listeria monocytogenes* is completely restricted. Gram staining indicated that AR-1 is a gram-positive bacterium, and whole genome sequencing and bioinformatic analysis demonstrated that AR-1 is classified as *Enterococcus mundtii*, and that its coding DNA strand (CDS) 02332 encodes a bacteriocin protein mundticin. Performing a Blastp search and Clustal Omega analysis revealed that this protein is highly homologous to enterocin or mundtii from other Enterococcus strains. Future assays include physical and biological analysis of the mundicin produced by AR-1, and purification/potential utilization of the mundticin as an anti-Listeria agent in food products.

ComposeGAN: Symbolic Music Style Transfer Using Generative Adversarial Networks and Chroma Feature Extraction

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Mentor: Shlomo Dubnov, University of California San Diego

ComposeGAN is a generative adversarial network that learns and transfers the style elements of music genres. Early attempts of symbolic music style transfer have faced the challenge of maintaining content while changing style during transfer. ComposeGAN presents a novel method to differentiate between style and content by embedding chroma feature extraction within the training process. A chroma is a visual representation of music that only records note density, separating style from content and improving the consistency of transfer. Three genres (pop, jazz, classical) were learned by the network for testing purposes. To evaluate the success of the transfer, two metrics were used: Tonnetz distance, to measure harmonic similarity, and a separate genre classifier, to measure transfer realism. The success of the transfer is evidenced by the high independent genre classifier accuracy rate and low Tonnetz distance, demonstrating a convincing style change and a conservation of content, respectively. This novel approach to genre transfer holds potential for future applications of GANs, as the representation that separates content from style can improve the consistency of other style transfer mediums like speech synthesis. Additionally, because of its transfer efficacy, ComposeGAN can be utilized as a tool for musicians to study compositional techniques and automatically generate music from lead sheets.

Smart Wildlife Warning Sign (SWWS): A Novel System to Protect, Track, and Conserve Wildlife with IoT and Machine Learning

Alan Ma
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Along the 10.6M km of roads in the US highway network, 59% of them cut through wildlife habitats. During migration seasons, these roads become barriers and traffic accident hotspots. [3] According to State Farm, 1 out of 116 US drivers have had a wildlife collision accident. In 2019, 1.9M large animal collisions occurred in the US and $1.1 billion were lost in insurance claims. [7] Roadkill accidents present a real danger to human society and wildlife populations. Existing methods to prevent roadkill are not very effective. One such is an animal traffic warning sign installed near areas of frequent animal activity. Traffic signs are passive solutions incapable of detecting animal activities and limited with poor visibility at night or bad weather. This results in short reaction times for drivers to avoid collisions. Other methods like animal overpasses and wire-fencing cost millions of dollars, are time costly to

build, and hard to maintain. These solutions become even more wasteful as animal behavior has been difficult to predict making permanent constructions ineffective without sufficient data. [2] This project demonstrates a novel, viable, and compact warning sign (SWWS) capable of detecting animal presence with smart sensors and actively providing visible warning signals for drivers to avoid roadkill accidents.

Testing the Efficacy of Transcranial Magnetic Stimulation on Psychiatric Comorbidities of Depression

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Mentor: Allison Stauffer, TMS Center of the Lehigh Valley

Transcranial Magnetic Stimulation (TMS) is a novel treatment for major depressive disorder (MDD), mitigating symptoms via stimulation of the basal ganglia of the midbrain. Approximately 60% of MDD patients are also diagnosed with comorbid psychiatric disorders such as GAD, OCD, and PTSD. Additionally, many patients who qualify for TMS have depression induced by Bipolar illness rather than MDD.

This study seeks to understand the potential of TMS as a treatment option for patients with GAD, PTSD and Bipolar Disorder as limited research has explored the efficacy of TMS in these illnesses. I hypothesize that TMS will be an effective therapeutic modality for this group of patients.

Patients with depression and other comorbid psychiatric disorders actively undergoing TMS therapy at a facility were enrolled in the study. The Beck's Depression Inventory, PCL-C, and SAS, were utilized to monitor progress throughout TMS treatments at 2 week increments. Symptoms on these scales were plotted to compare and analyze data. A control group with only MDD patients that took the same diagnostic surveys was set to provide a baseline of comparison. The mechanism of stimulation used to treat depression via TMS may be a viable treatment for other psychiatric disorders.

Novel Biomarker for Identification of Bipolar Disorder Treatment Response

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Mentor: Himanshu Mishra, University of California San Diego

Bipolar disorder (BD) is a genetically inherited mental disorder causing severe fluctuations between two mood sets: a manic and depressive stage. Few BD patients respond to the FDA approved mood stabilizer lithium, and nonresponders tend to commit suicide. It currently takes psychiatrists many months to determine lithium responsiveness, and only 34% of BD patients fully respond to lithium. Quickly determining lithium responsiveness would aid psychiatrists in being able to treat BD more efficiently. Pharmacogenomics has not yielded applicable results for a feasible genetic marker for lithium responsiveness. Therefore, discovering potential biomarkers for lithium responsiveness would assist with optimizing treatment strategies for BD. In order to discover biomarkers, recent studies have developed an accurate biological model for BD by using induced pluripotent stem-cell (iPSC) technology. Therefore, using iPSCs derived from BD patients that were lithium respondent and nonrespondent would assist with discovery of biomarkers for lithium responsiveness. My project used neural progenitor cells (NPCs) differentiated from iPSCs derived from BD patients that were lithium respondent and nonrespondent as well as control subjects. My results demonstrate that NPCs from control subjects and lithium nonresponders showed

significant cell death after exposure to the neurotoxic psychostimulant methamphetamine. Additionally, NPCs from lithium responders failed to show cell death after methamphetamine exposure. My study reveals that a lack of cell death by methamphetamine in NPCs from lithium responders could be used as a biomarker for lithium responsiveness. Taken together, my *in-vitro* system can be used as a platform for screening BD patients for lithium responsiveness.

Comparing the utilization of inorganic and organic phosphate in blue-green algal growth

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Teacher: Ann Marie Lipinsky

Mentor: Gregory Boyer, SUNY College of Environmental Science and Forestry

Harmful algal blooms, formed by blue-green algae that depend on phosphorus (P), are a major threat to freshwater. There are two main freshwater P forms: inorganic and organic P. Inorganic P is the more bioavailable form however some recent studies suggest that certain blue-green algae species preferentially use the less bioavailable organic P by producing alkaline phosphatase. I hypothesized that high inorganic P concentrations would cause the greatest growth because of its greater bioavailability and that alkaline phosphatase activity (APA) would be highest in a low organic P treatment as high APA can indicate P deficiency. I performed my experiment for two weeks during 2019 and 2020 and similar methods were performed for both years. Lake water was collected and divided into treatments of varying organic and inorganic P concentrations. Absorbance was calculated with a spectrophotometer to observe algal growth and APA was calculated by using Beer's Law. Standard error of the mean was calculated, and a two-sided T test was performed. The greatest algal growth occurred in the high organic treatment (0.050 absorbance units) and microscopic examination revealed that there were blue-green algae in the lake's microbial community with the ability to hydrolyze organic P, giving them a greater competitive advantage in the lesser bioavailable P treatment. As for APA, it was similar in all treatments after day 1. Although the findings regarding growth did not support my hypothesis, they help further support the idea that organic P can have real effects on freshwater health despite its lesser bioavailability.

Development of an Electric Wheelchair with a Wireless Electroencephalography-Based Control System

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Sponsor: Jacque Middleton

In our present time, many with physical disabilities find it difficult to access the help they need to improve their mobility. This project aimed to provide a solution for increased autonomy in the lives of the physically disabled using existing electroencephalography (EEG) technology. EEG is the process of recording electrical activity in the brain. EEG is commonly used in the medical field, such as in epilepsy diagnosis. As simple concentration can cause a change in this activity, EEG may offer a simple control mechanism for movement without the use of human limbs. While wheelchairs with assistive technology do exist, they are open to improvements in ease of use. The goal for this year's project was to construct an electric wheelchair with an intuitive EEG-derived control system and produce a confidence interval of the accuracy of a user controlling the chair using actions performed during a driving trial. For this project, accuracy is defined as the ratio of intended actions to all actions (intended actions, false positives, and false negatives). EEG control was achieved using a microcontroller-based hub with Bluetooth capability to interface with a modified EEG headset and electric motors. After the driving period, it can be projected with 95% confidence that the true probability of accurate control lies between 64.8% and 92.7%. This means that the

EEG-based control algorithm appears to have promising results for accurate control. However, further research will be required to improve the algorithm to achieve better accuracy.

Traveling Trout: Viability of Trout Eggs Along to Mainstem of the Geothermally Altered Alamosa River Watershed

Marissa Martinez
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Monte Vista, Colorado

Teacher: Loree Harvey

The purpose of this experiment was to expose rainbow trout eggs to water samples obtained from different points along the Alamosa River to see if water quality has improved since the Summitville Mine spill in the 1990s. I obtained fish eggs from a state fish hatchery, and created a prototype aeration system inside a stockroom refrigerator with beakers, nylon mesh, and zip ties. I placed 25 eggs into each beaker and continued to conduct daily water changes with specific sample water from each location. After analyzing my data, I found that the closer to Terrace Reservoir the sample location was, the larger the egg survivorship was. However, there were high concentrations of Aluminum, Copper, Iron, and Zinc in several locations which are known to be toxic to fish. Development data showed that some trout eggs died in Week One of the experiment, or successfully made it to Week Four, depending on the water treatment. Phosphates, Nitrites, Nitrates, Alkalinity and Hardness remained well below the toxic levels for trout. However, pH, Ammonia, and metal concentrations fluctuated within certain water samples throughout the course of the project. This study can be beneficial to Colorado Parks and Wildlife in terms of fish stocking and the restoration of the lower Alamosa River. My project merely scratched the surface of what can be understood in terms of trout egg viability and water quality within the Alamosa River watershed. There are additional healthy tributaries all along the Alamosa River that may support viable trout populations.

Compartmentalization in Lepidopteran Development: Anterior Posterior Boundary Location and Interaction in Genus *Morpho*

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Teacher: Paul Strode

Mentor: Nipam Patel, University of Chicago

Compartments in development are defined as separate cell populations that organize cell destiny and differentiation. Of particular interest is the anterior-posterior compartment. First analyzed in *D. melanogaster,* it is necessary to expand clonal analysis outside of simple model organisms to further the current extent of developmental knowledge. This study investigated the location of the anterior-posterior compartment in genus *Morpho* using clonal analysis with gynandromorphism as the coloration mutation for tracing. Specimens were adjusted in size and shape to fit a template before clones were traced. Fiji (ImageJ 2) analysis revealed that in the forewing, the boundary follows the M1 vein before bisecting the discoidal cell, and in the hindwing, the boundary is located between the M1 and M2 veins before similarly bisecting the discoidal region. There is a notable discontinuity in the curve of the boundary line that presents opportunity for further analysis related to

evolutionary advantage of discontinuous shape. The results of this analysis resolve the dispute regarding the location of the boundary.

Natural Occurence of a Visual Midline Shift in the General Population
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It has been assumed that a concussion can result in lasting vision problems, like a Visual Midline Shift. Many individuals suffer from a Visual Midline Shift following a Traumatic Brian Injury, such as a sport related concussion. The purpose of this study was to determine if there is a naturally occuring Visual Midline Shift in the general, non concussed population. This research holds value because if a naturally occurring Visual Midline Shift was found, that result would be cause for a re-evaluation of current concussion testing protocols. Participants in this study first completed a questionnaire detailing their concussion history. They were then assessed with the Visual Midline Shift Test, Near Point Convergence test, Pinwheel test and Visual Motion Test. The results showed that of the participants without knowledge of a previous concussion, 10 percent exhibited a naturally occurring Visual Midline Shift. Additionally, the results also showed that of the individuals with a history of concussion, 50 percent also exhibited a Visual Midline Shift. The rate of a naturally occurring Visual Midline Shift in the general non-concussed population found in this study was much higher than initially expected. The application of this study into diagnostic concussion testing would result in a fundamental change to the way concussions are diagnosed. Further study is warranted to create a widely applicable result due to the specific test group.

Improving Modifications for Virtual Instruction for Special Needs Population."
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If a student were presented with different reading methods to complete an assignment, those methods being text-to-speech, a human voice, and a read alone option, would the student better comprehend the human voice? The hypothesis stated was if a human reads the material being presented, the student will be able to better comprehend the information compared to a text-to-speech automation. The materials being used were four comprehension tests on google forms, one for the grades three, six, nine, and twelve. With three passages each with a different reading method including a read alone option, an automated voice option and a human reading option, each of these passages are followed by four short multiple-choice questions. The experiment was conducted by creating each google form for its corresponding grade level, inserting audio recordings for each passage and question, sending the forms out to students of each grade level to receive responses, then evaluating the responses to form a conclusion. Our research did align with our original hypothetical statement, in addition to improved comprehension most students preferred human voice readings. This is a win-win situation for educators because students can enjoy reading assignments and gain the intellectual benefits of an improved auditory learning system! One error that may have occurred during this experiment is students may not have made a wholehearted effort when completing the quiz. In future investigations we would like to survey students about their learning style, provide them with comprehension quizzes with various reading methods, then examine the results.

An Analysis of the Effects of Wetland Area on Algal Growth in Nearby Lakes in Eastern Nebraska
Elaina McHargue
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Central City, Nebraska

Teacher: Chelle Gillan

Many plants and wildlife rely on lakes and their surrounding areas for food, water, and shelter, and lakes are considered prime locations for real estate and recreation. However, with harmful algal blooms (HABs), caused by excess nutrients, becoming an increasing global concern, the survival of freshwater ecosystems is threatened. Wetlands remove nutrients from soil and water as roots of aquatic plants absorb nutrients, process them into gases, and release them into the air, which makes wetlands an essential part of reducing HABs. I designed this experiment to test the effects of wetland size on algal growth in nearby lakes. I combined water quality data from several Eastern Nebraskan lakes from the Nebraska Department of Environment and Energy (NDEE) and wetland area data from the National Wetlands Inventory. Much of this study was done using Geographic Information Systems (GIS), which combines spatial data relating to locations on the earth with attribute data, such as waterbody name or type of wetland. After running correlation tests, data were not conclusive enough to reject the null hypothesis that wetland area will not have significant effects on algal growth in lakes. I hope to have more opportunities to learn how to use technology such as GIS to contribute to the study of aquatic ecosystems in order to help landowners and government agencies make responsible decisions that promote environmental stewardship. Cooperation between organizations like the National Wetlands Inventory and the NDEQ are examples of how we can use technology to coordinate our efforts and drive research forward.

Processing Speed Subserves Sex Differences in Executive Function in Parkinson Disease

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Mentor: Dr. Elizabeth Disbrow

Parkinson disease (PD) affects more than 2% of individuals in the US over the age of 65. As a progressive neurodegenerative disorder, PD not only impacts movement, but also cognitive functions such as executive function and processing speed. Previous work from our lab indicates that PD females score higher on executive function and processing speed tests than males, while no differences were observed in our control populations. In this study, sex differences were further investigated, hypothesizing that sex differences in processing speed subserve differences in executive function, specifically inhibition and switching. By identifying cognitive differences by sex, significant differences can lead to differing treatment targets, potentially impacting the future of PD treatment by developing individualized treatment plans to reduce the signs, symptoms, and severity of PD in susceptible populations (males).

Retrospective analysis of a sample of 86 individuals (45% female, N=39) diagnosed with PD was performed. Demographic information including age (M=67.4), education (M=16.1, SD=2.7), and disease status were self-reported. Neuropsychological variables included category switching from the Verbal Fluency task of the Delis-Kaplan Executive Functioning System (D-KEFS) for switching, the Color-Word Interference and Trail Making Tests for inhibition, and the Symbol Digit Modalities Test (SDMT) for processing speed as a covariate.

While a significant difference by sex was revealed over time ($F(3, 88)=3.924$, $p=0.028$), a Repeated Measures ANCOVA analysis revealed that sex differences in SDMT processing speed accounted for more variance than sex ($F(3,87)=1.322$, $p =0.268$), indicating that changes in processing speed account for the observed sex differences in executive dysfunction.

An Algorithmic Approach to Simulating Human Cortical Bone Microstructure and Remodeling

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Baton Rouge, Louisiana

Mentor: Dr. Kevin Hoffseth, Department of Biological and Agricultural Engineering, Louisiana State University

The microscopic structure of bone contributes to its resistance to crack propagation and high damage tolerance under mechanical loading. In everyday life, bone accumulates tiny fractures, called microcracks. Bone exhibits a process of self-healing, called remodeling, that can replace damaged bone tissue with new healthy bone, effectively giving it a high overall resistance to damage. As people age, more microcracks form and remodeling tends to slow down, effectively increasing the number of microcracks in bone and raising the risk of catastrophic failure. This manifests in diseases like osteoporosis. Increasing our understanding of remodeling and bone's response to microdamage would allow for more effective treatments of these diseases.

The microstructure of bone consists of many interfaces within the material that slow or stop crack propagation. As 3D printing becomes more advanced, looking to structures found in the natural world, like bone, could guide the creation of stronger, more crack-resistant materials. In advanced material production, like engineering ceramics, this is a desirable property because the material will be able to undergo more severe conditions before it fails. Studying the distribution of these interfaces could provide a model to create improved materials.

The goal of this project was to create an algorithmic process that simulated the microstructure of cortical bone. This process could be used to study the microstructure geometry and effects of remodeling speed on overall bone microstructure. A better understanding of remodeling and microstructure, and how they affect each other, would create better experimental materials and treatments for common diseases.

Using Automated Infant Posture Recognition to Reduce SIDS Risk

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Mentor: Ulind Narang

According to the CDC, approximately 3500 infants die annually in the United States from sleep-related infant deaths, such as Sudden Infant Death Syndrome (SIDS). My project aims to reduce the extrinsic risk factors of SIDS by initiating an automatic alert when an infant's posture is high-risk (as considered by the American Academy of Pediatrics). I downloaded pictures of infants in various lying positions and produced about 50,000 video frames. On each frame, I ran PoseNet: a model that generates coordinates and a confidence score for different body parts. I used it to recognize each infant's nose, eyes, ears, shoulders, elbows, and wrists. I progressively added more features, such as angles and distances between certain body parts. Using this dataset, I built a geometric algorithm and a machine learning (ML) model. I changed the geometric algorithm to include threshold values for all measurements. Then, I imported the CSV data file into WEKA (an ML software) and experimented with different algorithms. The ML models with the lowest and highest accuracy were generated by Decision Tables (64.78%) and Random Forests (91.07%) respectively. After refining the Random Forests (RF) model by optimizing hyperparameters (objective functions and number of trees), the accuracy improved to 96.67% with a root mean square error of 0.072 when using 10-fold cross-validation. I incorporated this RF model into my "SIDS Pose Recognition" application. With my user-friendly app, caregivers would immediately receive an alert when an infant's position is unsafe or high-risk for SIDS.

Machine Learning on Crowd-sourced Data to Highlight Coral Disease; Empowering Citizens, Enabling Citizen-science

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Teacher: Dr. Arnold Kamhi

Mentor: Anthony J. Pellicano, Angion Biomedica Corp.

Coral reefs, which house millions of marine organisms and drive multibillion dollar tourism and fishing industries, have been under severe threat of bleaching due to the warming, acidification, and pollution of the oceans. Efforts are underway to track the extent of coral bleaching, however their reliance on human labor or limitation to benthic cover analysis makes them insufficient in diagnosing the full extent of bleaching. Proposed herein is a deep-learning approach that utilizes convolutional neural networks and crowd-sourced images – collected from governmental, academic, and personal sources – in order to develop a model capable of distinguishing healthy and bleached coral. The researcher sourced hundreds of images from government archives, the Coral Reef Image Bank, and ecological papers and annotated these images to highlight healthy and bleached corals using the Labelbox platform. The Mask R-CNN (Region-based convolutional neural network) algorithm was trained, validated, and tuned to find optimal hyperparameters, on these images within an Amazon Web Services EC2 instance. The model that performed best on the training and validation sets was tested on an independently-curated set of images and a precision-recall curve was constructed to determine the optimal operation point, or confidence threshold. Training yielded a model with an 85% accuracy in differentiating between healthy and bleached corals in subaquatic images. This deep-learning based model can be implemented in global databases of images from academic explorations and tourist travels in order to track the incidence of bleaching, thereby informing allocations for treatments and preventative measures to preserve our marine ecosystems.

DeepWaste: Applying Artificial Intelligence for Waste Classification to Combat Climate Change
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The Nueva School
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Teacher/Mentor: Tanja Srebotnjak

Accurate waste disposal, at the point of disposal, is crucial to fighting climate change. When materials that could be recycled or composted get diverted into landfills, they cause the emission of potent greenhouse gases such as methane. Current attempts to reduce erroneous waste disposal are expensive, inaccurate, and confusing. In this work, we propose ***DeepWaste***, an easy-to-use mobile application, that utilizes highly optimized deep learning techniques to provide users instantaneous waste classification into trash, recycling, and compost. We experiment with several convolution neural network architectures to detect and classify waste items. Our best model, a deep learning residual neural network with 50 layers, achieves an average precision of 0.881 on the test set. We demonstrate the performance and efficiency of our app on a set of real-world images.

Comparative analysis of transcriptome changes in *Solanum pennellii* pistils before and after flowering time
Samira Nassi Celaya
Tucson High Magnet School
Tucson, Arizona

Teacher: Mr. Jonas

Mentor: Dr. Warman

Sponsor: Dr. Palanivelu, Palanivelu, University of Arizona

Increasing global temperatures pose challenges for efficient pollination in food crops. A measure to prevent yield loss is to breed thermosensitive crops with thermo tolerant crops. Establishing a bioinformatic pipeline to compare two transcriptomes of plants is needed to identify key gene candidates for thermotolerance. Since none exists, an existing transcriptome dataset of *Solanum pennellii* before and after flowering was utilized for the application of bioinformatics in search of gene candidates for unilateral interspecific incompatibility(UI). These gene candidates should be highly expressed after flowering because upon pollination, the style must be prepared to deny pollen from itself and other species when it's able to be pollinated.The tissues of *S. pennellii* were mapped to a reference genome with STAR using the UA HPC system. Differential analysis and visualization were conducted in R with the DESeq2 function. Several differentially expressed transcripts identified in this study code for proteins involved in signaling pathways, which are likely necessary for maintaining UI. Therefore, this study identified candidate genes/proteins for key aspects of UI. Further characterization and functional validation of candidate genes is necessary to link these changes in expression to biological functions. This proof of concept study suggests that a similar bioinformatic analysis could be used to identify thermotolerant genes and proteins when the associated transcriptomes become available.

Where the Rubber Meets the Road: The Development of an Innovative, Reusable, and Energy-Efficient Filter for Microplastics Created Through Tire Wear

Jennifer Oettinger
Mayo High School
Rochester, Minnesota

Mentor: Ann Oettinger

The purpose of this project was to develop and test a reusable and energy-efficient device to filter microplastics (plastics under 5mm in size) created by tire wear. This research is important as tire wear accounts for up to 28% of microplastics in the oceans, makes up 3 to 7% of the particulate matter in the air, and U.S. tires alone produce about 1.8 million tons of microplastics every year. There is currently no realistic alternative tire design that does not produce microplastics. This project modified an electrostatic smoke precipitator design to create a filtration device. A series of 9-volt batteries were used as the power supply for this filter. For this experiment a tire was run over a file for 35 seconds to simulate road wear, the filter was placed behind the tire, and a glass collection box was placed behind the filter. Afterwards microplastic particles in the collection box were counted. The results showed that the average number of plastic particles was reduced from 557 to 74 when the tire’s airstream was not filtered versus when the 108V filter was used. This 87% reduction was the greatest of any voltage tested, with the 0V filter having a 1% increase, the 27V filter having a 57% reduction, the 54V filter having a 74% reduction, and the 81V filter having a 79% reduction in comparison to the non-filtered airstream. Based on these results, it can be concluded that this electrostatic filter is effective at addressing microplastic pollution created through tire wear.

Plant Growth Enhancement & Fungal Disease Suppression via Copper, Zinc, and Manganese Nanoparticle Foliar Sprays

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Mentor: Andrew Bramante

Sensitive crop regions are constantly under environmental stresses that foster plentiful plant disease. Basil plants, for instance, have been victims of *Fusarium oxysporum (F.o.)* wilt for decades, where growth conditions have stimulated progression of this disease, and subsequent crop destruction. A simple and effective treatment that

would eradicate *F.o* wilt, while promoting overall plant growth, is needed. Metallic nanoparticles (NPs) have shown to improve plant health and overall crop yield, due to systemic movement through the plant's root system, where the nutritional value of metallic nanoparticles is fully realized. This research investigates whether the "foliar-spray" application of NPs of copper, manganese, and zinc (as oxides) increases the growth rate and crop efficiency of healthy *O. basilicum* plants, and inhibits the adverse effects of *F.o*., to ultimately devise an easily-applied, simple, and effective treatment to promote increased crop growth. Pre-grown (3") basil plants were first transferred to ~0.8L pots using ProMix-BX soil, which was pre-inoculated with 1-2ml of 1g/L-*F.o* in water. Each plant was then treated with ~2ml foliar spray of the respective nanoparticles. After 6 weeks growth, all three MO-NP treatments produced significant increases (>120%) in biomass, relative to diseased plants; ZnNPs were the most favorable, at 180% increase in biomass relative to untreated, diseased plants. Combined Cu-Zn NP treatment enhanced diseased plants' biomass by 29% and provided a 40% increase in height. Most importantly, diseased-plants outgrew healthy controls by 21%, highlighting the treatment's ability to fully suppress *F.o.*, so that infected plants grow beyond normal, healthy conditions.

Determining the effects of added zinc on plants

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Louisville, Kentucky

Teacher: Belinda Hafell

The purpose of the study was to determine the effects of added zinc on plants, specifically *Vigna unguiculata subsp. unguiculata,* on the height of the plants and the chlorophyll content in the leaves. Zinc contamination soil is becoming more and more of an issue, as soil is a finite resource and soil pollution impacts crop yields and quality. It was hypothesized that if the amount of added zinc was greater than 200 ppm, plant growth would decrease, and chlorophyll content would decrease. If the amount of added zinc was between 0 and 200, plant growth would increase, and chlorophyll content would increase. To test the hypothesis, forty *Vigna unguiculata subsp. unguiculata* plants were planted in forty Styrofoam cups, with 100 grams of sterilized organic soil in each cup. The plants were divided into four groups, and each group received 0 ppm, 100 ppm, 200 ppm, or 300 ppm of zinc sulfate fertilizer. Sixteen milliliters of water was given to the plants every day, and height measurements were taken every alternate day. Chlorophyll concentrations were determined through the use of a colorimeter; this was done once at the end of the experiment. Based on the results of the t-tests performed, it can be concluded that there may be an impact on chlorophyll content in leaves when zinc is added to the soil ($p<0.05$), but there is no statistically significant impact on adding zinc to the soil on the height of *Vigna unguiculata subsp. unguiculata* ($p>0.05$).

Isolation, Sequencing, and Annotation of Novel Bacteriophage

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Teacher: Nicole Rosen

Mentor: Joel Schildbach, Johns Hopkins University

Antibiotics are the most common treatment for bacterial infections. However, as bacteria develop antibiotic resistance, treatments are becoming less effective. One solution to this problem is bacteriophages, or phages, which are viruses that infect and kill bacteria. Phage research holds promise, as phages target specific pathogens without affecting harmless bacteria. In order to further the field of phage research, it is crucial to expand the dataset of discovered phages. Each phage has a specific host range, so having a wider scope of discovered phages enables a more comprehensive range of bacteria to be targeted and possibly treated. For this project, five distinct phages were identified, isolated, purified, and concentrated into lysates (aqueous phage samples). The concentration and morphology of each phage were determined, and the samples were sequenced. The results from sequencing yielded three novel bacteriophages. Ideally, to complete this process, these sequenced genomes would be annotated and added to the Actinobacteriophage Database. Due to COVID-19, this was not immediately possible, so instead, the genome of previously sequenced Cluster M1 phage SirSheldon was annotated. A genome announcement was written for that phage. Through this project, the bank of discovered phages was increased as well as the understanding of the M1 phage cluster.

Dataset-Agnostic Vessel Segmentation of Retinal Fundus Images by a Vector-Quantized Variational Autoencoder

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Sponsor: Shruti Prabhune

The use of retinal fundus images plays a major role in the diagnosis of various diseases such as diabetic retinopathy. Doctors frequently perform vessel segmentation as a key step for retinal image analysis. This is laborious and time-consuming; AI researchers are developing the U-Net model to automate this process. However, the U-Net model struggles to generalize its predictions across datasets due to variability in fundus images. To overcome these limitations, I propose a cross-domain Vector Quantized Variational Autoencoder (VQ-VAE) that is dataset-agnostic – regardless of the training dataset, the VQ-VAE can accurately classify vessel segmentations. The model does not have to be retrained for each different target dataset, eliminating the need for new data, resources, and time. The VQ-VAE consists of an encoder-decoder network with a custom discrete embedding space. The encoder's result is quantized through this embedding space then decoded to produce a segmentation mask. Both this VQ-VAE and a U-Net model were trained on the DRIVE dataset and tested on the DRIVE, IOSTAR, and CHASE_DB1 datasets. Both models were successful on the dataset they were trained on – DRIVE. However, the U-Net failed to generate vessel segmentation masks when tested with other datasets while the VQ-VAE performed with high accuracy. Quantitatively, the VQ-VAE performed well, having F1 scores from 0.758 to 0.767 across datasets. My model can produce convincing segmentation masks for new retinal image datasets without additional data, time, and resources. Applications include using the VQ-VAE after the fundus image is taken to streamline the vessel segmentation process.

Spira Mirabilis 2: Optimizing the Performance of Logarithmic Spiral Wind Turbine

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Sponsor: Aily Salikin

Mentor: Dr. Alireza Asgari, 3M

Wind energy is cost-effective and non-polluting, but only makes up 2% of the US electricity generated. Small-scale wind turbines don't operate efficiently below 30m due to turbulence, which creates drag on the turbine and reduces efficiency. The goal is to develop higher efficiency Logarithmic Wind Turbines (LWT) in multiple directions of wind at low speeds.

LWT turbines were developed in 2 Phases, changing the tip angle, height, and width. Prototypes were 3D-printed, with the stand and generator connected for testing at different wind speeds and latitudes/longitudes. Power was measured using multimeter. Efficiency was calculated by comparing LWT power to the power available in the sweep area. Flow simulations helped visualize wind flow.

The blade surface area to sweep area ratio (aspect ratio) is optimal between 2.7-3.0, with the highest efficiency at 45.3%. Lower tip angles have higher efficiency, with an optimal point at 15°. New and improved stand design reduces wind blockage and increases efficiency. The latitude/longitude of the wind affects power generated.

The data supports my hypothesis as the blade's tip angle, height, and width affect the wind energy captured. High aspect ratio decreases pressure and allows more air to flow through without much disturbance, incurring the Coanda effect. Low aspect ratio increases pressure and creates turbulence, diminishing the Coanda effect. Optimal aspect ratio is where wind flow is captured in the turbine, causing disturbances, without much turbulence, while benefiting from the Coanda effect. With peak efficiency at 5-8m/s, LWTs are suitable to be deployed both locally and globally.

A Novel Methodology to Direct Scientists to Dramatically Improve the Reliability and Robustness of AI Forecasts (via Mitigation of Biases)

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Teacher: Vladimir Shapovalov

Mentor: Dr. Erick Scott

Class imbalance occurs in binary classification when the training dataset contains more instances of positive cases than controls. The model then carries this bias when making predictions. Model bias has hindered the effectiveness of COVID-19 prognosis models, amplified racial discrimination, and is prevalent in cancer diagnosis models. I further confirmed this by using the standard bootstrap method in different case frequency contexts and highlighted its inability to consistently discriminate between models. ImbDis, a novel metric, addresses this. ImbDis compares the performance of models by creating data sub-samples and systematically varying the case frequency. In each sub-sample the accuracy is scored using a desired accuracy metric such as the AUC-ROC and Brier Score. I then used synthetic data as well as a breast cancer dataset to train Random Forest, Decision Tree, and Logistic Regression models and assessed model performance using ImbDis. ImbDis succeeded in showing which models are better suited than others to be used in various case frequency contexts. This insight would be unachievable otherwise. A novel metric like ImbDis will allow researchers to determine which model has the least bias in their desired situation. In turn, this will allow them to minimize the effects of bias caused by a class imbalance in the data

Implementation of Human Urine and Cellulose Nanomaterials as a Visual Arsenic Assay and Accessible Arsenic Remediation Method

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Advisor: Christopher Reeves

Aquatic arsenic poses a great threat to global health and is present at levels significantly over the maximum level acceptable as labeled by the United States Food and Drug Administration in many locations across the world. Consuming this arsenic causes DNA inhibition, cancerous growth, and respiratory failure, among other health concerns.

Though tests and treatment methods for aquatic arsenic exist, most are inaccessible to the common citizen regardless of their location. This research was conducted in order to develop a globally accessible visual test and simple remediation method for aquatic arsenic.

A visual test was designed to identify arsenic concentrations visually through application of carbon dots synthesized from human urine as fluorescent nanosensors. This assay can be easily recreated and offers a clear visual distinction between arsenic levels in water samples. Significant differences (p-value < 0.05) in absorbance and transmittance supported this visual gradient.

A remediation method was designed to convert any present arsenite to arsenate and subsequently absorb this arsenic from the water, rendering the sample potable. This design involved implementation of carbon dots as a photocatalyst for conversion of arsenate into arsenic, followed by absorption by cellulose nanomaterials. Significant reduction of arsenic presence in treated samples (p-value < 0.05) supported this process as a viable remediation method. Such a process can be easily replicated using human urine and any available carbon material, namely plant mass.

Detection of *C. parvum* Transposons in Potable Water Using Genetically Engineered Bioelectric Sensors

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Highlands Ranch, Colorado

Mentor: Dr. Michael McMurray, University of Colorado, Denver

Cryptosporidiosis (Crypto) has a substantial health impact globally, particularly in lower-income countries and is the most common cause of waterborne disease in the world.

My inspiration was drawn from Kakuma refugee-camp who commonly find cryptosporidium, also known as *C.parvum,* in their water. Current methods for detecting cryptosporidium require filtering large volumes of water and identifying the pathogen using a microscope.

With genetic-engineering, the research goal is to develop a real-time solution for common people to indicate the presence of *C.parvum* in potable-water.

The proposed solution uses CRISPR-cas9 to edit B. cereus microbe genetically, trigger a bioremediation pathway, and release an electrical impulse when C.parvum is identified. Gold-based electrodes and voltmetric transducers convert electrical impulse values into a digital voltage displayed as a directional result in a mobile-phone app.

My work involved simulating the creation of a genetically-engineered B.cereus microbe and creating a correlation-map between the concentration of C.parvum and voltage released. A device was designed to measure the electric impulse using a biosensor. The detection works without the need for complex preparations and highly-trained technicians.

In future, the test-results will be verified with the device-prototype. The solution can be expanded to detect other parasitic contaminants.

Targeted Delivery Of Immune Agonists For Antitumoral Response Of The Tumor Microenvironment

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Mentors: Peter Bielecki and Efstathios Karathanasis, Department of Biomedical Engineering, Case Western Reserve University

Tumor-mediated immunosuppression allows tumors to hide from the immune system and avoid recognition. To reverse suppression, antigen-presenting cells (APCs) and other immune cells within the tumor can be targeted and activated from their senescent states. Cyclic diguanylate monophosphate (c-di-GMP), a drug that works within the cytosol of immune cells, is used to release inflammatory cytokines like IFN-β to recruit immune cells and initiate anti-tumor responses. However, freely injected c-di-GMP cannot cross cell membranes and is quickly cleared from the body. It is hypothesized that c-di-GMP loaded into a nanoparticle will more effectively deliver drug into immune cells, which are widespread within the tumor, resulting in more potent therapy. To demonstrate the system's therapeutic potential, macrophages were exposed to 30 μg of c-di-GMP loaded into nanoparticles *in vitro*. C-di-GMP nanoparticles boosted cytokine IFN-β production from murine macrophages by 6-fold compared to free c-di-GMP, while unloaded nanoparticles induced low levels of IFN-β secretion comparable to untreated macrophages. This work shows promise in increasing immune agonist efficacy by targeting and reversing immunosuppressive cell subtypes, especially in aggressive cancers, notably breast and brain cancers. Recent advancements support extending this platform to regulate expression of the inhibitory immune-checkpoint protein V-domain Immunoglobulin Suppressor of T-cell Activation (VISTA). Ongoing work utilizes computational methods to synthesize small-interfering RNA (siRNA) for delivery to the tumor site to regulate VISTA expression. Future work includes *in vitro* and *in vivo* studies testing efficacy of synthesized siRNA molecules, optimizing delivery of nanoparticles, and evaluating therapeutic effects on tumor burden and overall survival.

A Study of Effective Water Filtration Using Natural Resources Available in Puerto Rico

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Sponsor: Herald Roettger

Puerto Rico is an island that is frequently impacted by natural disasters, which can cut out power and leave people without everyday resources, such as drinking water. Our team, Aguarico, decided to find a solution for this problem. We developed our research questions: (1) How can we create an effective and easily-accessible water filtration system to ensure safety of water quality for people in Puerto Rico who may not have access to drinking water, especially after a natural disaster? And (2) What are the similarities and differences between a filtration system using coconut husks, charcoal, and sand and a filtration system using banana peels, sand, and cilantro in the context of coliform, enterococci, dissolved oxygen, nitrates, water transparency, and pH? Based on these questions, we created two filtration systems. We found that our first prototype was able to remove all tested bacteria from both city and irrigation water samples. Our second prototype left one unit of enterococci bacteria in irrigation water. After we compared our data, we determined that, while our first filter, which implemented coconut husks, coconut charcoal, and sand was effective in purifying water, our second filter, which utilized banana peel, cilantro, and sand was more practical and easy to build. Both of these filtration systems proved to have potential for use in

the aftermath of natural disasters. In the future, we hope to provide more outreach in our community to raise awareness about the usefulness of a natural, affordable filtration system, helping those without access to safe drinking water.

Green Infrastructure Impacts on Carbon Cycling: Evaluating Changes in Soil Microbial Composition and Function
Isabel Ross
Cienega High School
Vail, Arizona

Mentor: Dr. Vanessa Buzzard, School of Natural Resources and the Environment, University of Arizona

This project aimed to identify how the implementation of green infrastructure (GI) water harvesting systems impacts the carbon cycle by studying shifts in microbial composition and function. To conduct this study, a GI system was created in a residential area in Tucson, Arizona with greywater, active, passive, and control basins. The microbes present in the soil were identified from16S rRNA PCR samples using a program called FAPROTAX. This program mapped the identified microbes to associated metabolic functions. I then conducted an extensive literature review to link the identified microbes to functions they have been proven to perform. Although all microbes and their functions were explored, I focused on decomposition pathways and two functions involved in the breakdown of cell walls and exoskeletons, making them key for decomposition: chitinolysis and cellulolysis. I found that both chitinolysis and cellulolysis have higher relative abundances in all GI systems compared to the control. This demonstrates that GI water harvesting treatments do impact soil microbial composition and function, suggesting that GI does alter the carbon cycle. This could have possible impacts on climate change, as carbon is a major greenhouse gas. Further research should investigate this by measuring soil respiration in GI systems. GI systems may also increase the availability of key nutrients by releasing locked compounds stored within strong cell walls and exoskeletons. Increases in bioavailable compounds can lead to greater access by other organisms such as soil invertebrates and plants, supporting growth and diversity, so this could be a focus of further research.

Discovery and Spectroscopy of a Young Jovian Exoplanet with the ALADIN and Systemic Database
Ramzi Saber (1st place, Physical Sciences)
Jose Marti STEM Academy
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The star system HD-92788 was investigated for 3 years concerning its astronomical properties. During the summer of 2017, a theoretical study was conducted on the young star system 113 light years away with the goal of determining the likelihood of the existence of an exoplanet around the system. Through mathematical principles such as CHI2 and radial velocity of the star system, it was concluded that there is theoretical evidence that a large Jovian planet is orbiting around HD-92788 with a CHI2 value of 1.99. During the summer of 2018, a new study was conducted attempting to capture the exoplanet in orbit. Based on the mathematical and statistical data collected during the previous summer, the predicted exoplanet would appear during the months of February and March. The study was a success due to the manipulation of the ALADIN database, an interactive software sky atlas updated every month that allows the to superimpose visual entries from astronomical catalogs, and to interactively access related data and information. Visual proof of the exoplanet was captured, and it was seen to be approximately 3 times the size of Jupiter. During the summer of 2019, chemical studies were conducted that showed that this exoplanet possessed Jovian characteristics.

Alcohol Addiction: The Role of Secreted Inflammatory Cytokines (IL-6 and IL-1β) in Crossing the Blood-Brain Barrier and Altering Neural Function
Harnoor Sachar (1st place, Biomedical Sciences)
Bergen County Academies
Hackensack, New Jersey,

Teacher/Mentor: Donna Leonardi

In 2012, 5.1% of the burden of disease and injury worldwide was connected to alcohol consumption, which is why there is reason to believe that it is not just receptor inhibition that results in alcohol's detriments, but rather there are additional ways that it harms the body (specifically the brain). This study aimed to find which cytokines are secreted in the liver as a result of alcohol addiction, and how the cytokines affect the cellular microenvironment, potentially opening the door to many diseases. The hypothesis was two-fold: (1) The IL-6 protein production (inflammation) will increase in alcoholic liver cells (2) The IL-1β protein (immune response) production will decrease in alcoholic liver cells. The research presented here found that when HepG2 cells were treated with ethanol for 24 hours, cell proliferation decreased by ~120% in the 3% and 4% concentrations, and for 48 hours, cell proliferation decreased by ~110% in the 3% and 4% concentrations. Then, ELISAs were conducted in order to test for IL-6 (*$p<0.05$ in 3% and 4%) and IL-1β (*$p<0.05$ in 3% and 4%) to reveal which particular cytokines are secreted in alcohol-treated cells and at which concentrations they are statistically significant. The ELISAs revealed that IL-6 protein expression increased at 3% and 4% ethanol, while IL-1β protein expression decreased at 3% and 4% ethanol. The results indicate that alcohol addiction is associated to increased inflammation, which can lead to cell & DNA damage, and decreased immune response, which leads to frequent infection & diseases.

Designing Impact Resistant STF Composites For Various Weather Conditions
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Chamblee Charter High School
Chamblee, Georgia

Teacher: Shaheen Begum

Millions of sports and recreation-related injuries occur each year. Shock absorbing composites using shear thickening fluids (STF) or dilatant materials were fabricated and tested with the goal of exploring their potential as protective sportswear. The effect of varying weather conditions on STF composites made of Silica and Propylene Glycol and the role of additives in the STF mix in mitigating impact shock were studied.

Drop tests were conducted by releasing a 1.1 lb weight from an electromagnet on fabricated STF composites. The impact force for each sample was measured with an electronic sensor. The shock absorption percentages for each sample was calculated from the forces obtained from the drop tests. The weight and height of the drops were chosen based on typical forces of an impact that would cause injury in sports. The samples were also subjected to 0 degrees F, 70 degrees F, and 105 degrees F before testing.

A composite of Nylon fabric and Silica-propylene glycol-carbon nanoparticles STF mix displayed better shock absorption behavior than other fabricated STF composites with different additives in all tested temperatures. The Silica-PG-Carbon composite also performed 10% better than commercial proprietary shock absorption materials such as D30, Poron, Sorbothane, and Auxadyne. STF composites deteriorated at higher temperatures, but the carbon and cerium oxide additives greatly reduced the amount of degradation.

The study successfully demonstrates that STFs can be used to fabricate high-performing protective composites for sportswear and other shock-absorbing applications.

Comparing Outcomes of COVID-19 Positive Individuals with and without Chronic Kidney Disease using Python and CoRDaCo
Safiya Sankari

Eman Schools
Fishers, Indiana

Mentor: Dr. Eneida Mendonca, Regenstrief Institute

As of January 3rd, 2021, there have been 1,839,622 deaths globally and 84,838,747 cases globally caused by COVID-19. Simultaneously, an estimated 15% of U.S. adults suffer from Chronic Kidney Disease (CKD). Individuals with CKD may be particularly vulnerable to COVID-19 as they have larger amounts of circulating ACE2, and ACE2 is the main target of COVID-19. This study is focused on understanding how the comorbidity of CKD impacts patient outcomes for COVID-19 positive individuals. Outcomes were defined as emergency department visitation rate, median length of inpatient stay, inpatient admission rate, and mortality rate. Patients over the age of 18 who tested positive for COVID-19 between January 1-July 13, 2020 were included in this study from over 100 healthcare entities. The median Charlson Index for the CKD COVID-19+ (n=1,946) cohort was 4 and for the Non-CKD COVID-19+ (47,478) cohort was 1. The CKD COVID-19+ cohort was comprised of 52.5% women and 47.5% men . The Non-CKD COVID-19+ was comprised of 54.1% women, 45.4% men, and 0.5% other. The Non-CKD COVID-19 + and CKD COVID-19+ cohorts were further divided into 4 age-by-race subcategories, as race and age were found to be significantly correlated with CKD. The CKD COVID-19+ cohort had statistically higher ($p<.05$) ED visitation rates, mortality rates, and inpatient admission rates for all subcategories in comparison to the Non-CKD COVID-19+ cohort. This study demonstrates that CKD may be associated with a higher severity of COVID-19 outcomes. Further research must be done to manage confounding variable and study this association more extensively.

A Flexible DLP 3D-Printed Coated Microneedle Patch for the Delivery of New Therapeutics to Citrus Stem Tissue

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Teacher: William J. Furiosi II

Research Advisor: Professor Swaminathan Rajaraman

This work reports the design, fabrication, and testing of a flexible digital light processing (DLP) 3D-printed coated microneedle patch, designed for transporting copper-based therapeutics to the stem tissue of Huanglongbing (HLB)-affected trees. HLB has decimated the previously $9 billion citrus industry in Florida, reducing citrus-producing acreage by more than 50%. HLB is caused by a phloem-limited bacterium "*Candidatus* Liberibacter asiaticus" (*C*las), so any treatment must be delivered to phloem tissue to be effective, demanding the need for an innovative, user-friendly delivery mechanism that can bridge the gap of testing between the lab and the grove. It was hypothesized that a coated microneedle patch will efficiently create penetrations into the stem by which treatments can reach the thin stem phloem. Based on multiple therapeutic selection criteria, metallic copper was selected and used for this study. Copper is formulated using a suitable emulsifier so it can be released in a sustained manner and copper toxicity in vascular tissue is minimized. The microneedles were designed to have an optimized surface area for maximizing the formulated copper coating. The amount of copper released from several coated microneedles into water was quantified for a period of 48 hours using Atomic Absorption Spectroscopy (AAS). The AAS data confirm maximum copper release from the microneedles within 24 hours. The microneedles created consistent and uniform penetrations into citrus sapling stem tissue that reached the phloem. Work in progress includes the testing of the device prototype in vitro in lab conditions to optimize parameters required for field environments.

A Weakly Supervised LSTM Model for Longitudinal Breast Cancer Recurrence Prediction via Unstructured Clinical Narratives

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Homestead High School

Cupertino, California

Mentor: Dr. Imon Banerjee, Emory University School of Medicine

For the 3.5 million breast cancer survivors in the US, there is an almost 30% probability of recurrence, of which 1-1.5% are potentially curable due to late detection. Earlier prediction of recurrence could improve survival, increase quality of care, and save medical resources. Previous studies have attempted to predict recurrence using structured electronic health records, but lack of standardization in recurrence surveillance and missing EHR data makes such models unsuitable in clinical settings. While widely-available clinical notes may offer the greatest detail about patients, they are largely unexplored due to the challenge of representing free-text data for computational analysis. In this study, I present the first attempt to predict breast cancer recurrence, 1 year in advance, by leveraging unstructured clinical narratives over a patient's visit sequence. To deal with the noisy, unstructured nature of free-text notes, I propose a weighted vectorization scheme to represent clinical narratives without supervision and train it on 92.6 million notes across 3 institutions. The recurrence prediction model is then trained jointly on manually curated data from 1519 patients and weakly labeled data from 7437 patients, achieving 0.94 ROC AUC when validated on holdout test patients. This weak supervision approach improves accuracy with less manual effort, by enabling the usage of realistic clinical datasets where cancer recurrence occurs in a minority of patients. The model's longitudinal approach also allows for visualization of predicted recurrence probabilities over time, helping clinicians rationalize its outcomes, incorporate them into patient treatment, and potentially prevent recurrences.

Smart robot to purify, humidify, and disinfect the air
Mikul Saravanan
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Teacher: Dr. Stephanie Kokoszka

Maintaining optimal indoor air quality (IAQ) and humidity is a critical aspect of improving overall health. Low IAQ leads to respiratory illnesses, while low humidity causes dehydration and dryness. To a limited extent, stationary air purifiers and humidifiers address the issues of low humidity and IAQ. I experimented with multiple humidity sensors (hygrometers) placed throughout a room that showed a standalone humidifier could not distribute humidity evenly within the space. I solved the uneven distribution issue with a smart moving robot containing an air purifier, humidifier, and Ultraviolet C (UVC) lamp. The UVC lamp disinfects air by killing most bacteria as well as viruses such as COVID-19 This is highly applicable in light of the recent COVID-19 pandemic. My custom-built robot uses a Raspberry Pi, a camera, and sensors to detect air quality and humidity. The robot and the air handling system were modeled in Computer-Aided Design (CAD) and analyzed with Computational Fluid Dynamics (CFD) to find the various components' optimal design. I built the robot on a wooden platform that contains the electronics, air purifier, UVC lamp, and humidifier system. The robot was programmed to navigate a room until it detects dry air to humidify and polluted air to purify. I created an AI-based object detection algorithm with TensorFlow Lite to detect people. If the robot detects people, it disinfects the air in that area for a longer period of time. My experiment shows that the robot was able to humidify a room more evenly than a standalone humidifier.

Orthologs for Pigmentation Genes in *Schistocerca gregaria* are Candidates for Body Color Change During Locust Phase Transition
Sreeram Satish

William P. Clements High School
Sugar Land, Texas

Mentor: Dr. Herman Dierick, Baylor College of Medicine

Schistocerca gregaria, the desert locust, frequently swarms the plains of Africa and Asia, destroying the food supply for millions of people. The species transitions between differently pigmented solitarious and gregarious (swarming) phases. The genetic and biochemical bases of pigmentation are understood in several model organisms, most notably the fruit fly, *Drosophila melanogaster*. We hypothesized that pigmentation genes in *S. gregaria* orthologous to those in *D. melanogaster* may play a role in the color changes that occur during swarming. To identify candidate pigmentation genes, we used publicly available data from the FlyBase, NCBI, and OrcAE databases to search for three known *D. melanogaster* dark pigmentation genes, *black*, *tan*, and *ebony*, in the draft genome of *S. gregaria*. Due to the evolutionary gap between the two organisms, some orthologous genes were difficult to detect. To bypass this issue, we used the German cockroach, *Blatella germanica*, as an intermediate organism because it is more closely related to *Drosophila melanogaster* and has a well-annotated genome. We developed a workflow to annotate *D. melanogaster* orthologs in *S. gregaria* and found one candidate ortholog for *ebony*, one candidate ortholog for *tan*, and two candidate co-orthologs for *black*. We plan to confirm these candidate pigmentation genes by analyzing RNA from *S.gregaria* and related locust species with completed transcriptomes. We will also analyze expression differences between swarming and non-swarming locusts and continue to look for other pigmentation genes. Ultimately, we want to knock out these genes in grasshoppers to test their role in pigmentation causally.

The Development of an Improved Wireless Energy Transmission System and Adapter

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Teacher/Sponsor: Dr. Joshua Swartz and Dr. Ann Ouyang

Existing systems of wireless energy transmission (WET) are traditionally only used in extremely controlled environments with a small range of efficiency. The cause of this shortcoming is the use of resonant inductive coupling[1] which requires a small distance between primary and secondary and a controlled medium to operate for use with consumer electronics. The alternative method to transfer energy wirelessly through air is to utilize intentional parasitic capacitance between the secondary of a Slayer Exciter Circuit (SEC) and ground. A SEC was constructed and driven off of a 12v and 2A power supply into a 3:800 turn transformer to maximize parasitic capacitance. A receiver coil with 200 turns was constructed to receive power from the field that the SEC generated. The received energy was fed into a rectifier and was able to provide power to a circuit. To measure the area of the field excited, a 13W fluorescent lightbulb was moved to varying distances from the SEC, where it was determined how far ay the light could be excited. This distance came out to ~60cm depending on environmental conditions. To measure the strength of the same field a LED was placed on the rectified output of the receiver and was able to illuminate at a range of ~50cm depending on environmental conditions. This method of WET was able to transmit energy in, at worst, parity with traditional resonant inductive couplers. These results support the hypothesis that further research into SEC WET may yield a better form of WET than resonant inductive couplers.

Examining the Role of Race in the Cook County Criminal Justice System

Lauren Schmidt
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DoDEA Stuttgart, Germany

Mentor: Daniel Coapstick

The criminal justice system of the United States is increasingly affected by racial bias in all aspects, from charge and arrest to the trial process to incarceration and recidivism rates. This study examines the trial process and judges in

particular in Cook County (Chicago), Illinois due to its high crime rates. Through a set of statistical analyses and disposition and sentencing data from the Cook County Courthouse, it is shown that there is a disproportion in the number of Black defendants and convicts to White defendants and convicts. Additionally, the proportions of Black judges to White judges show a much greater number of White judges overall. Placing the results of the analyses and statistical tests in a broader context shows that judges, juries, and trial courts are one of many components to determining racial bias in a city's criminal justice system, and that while showing an abnormal bias, the results from this study alone cannot definitively deem the Cook County Courthouse responsible for the observed bias.

Enabling High-Accuracy Human Activity Recognition with Fine-Grained Indoor Localization
Arvind Seshan
Fox Chapel Area High School
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The ability for computers to determine a user's current physical activity (e.g., running, cooking, and shaving) could enable a wide range of applications, including health monitoring and context-specific assistance. Current systems for Human Activity Recognition (HAR) require diverse sensor types (eg. cameras, proximity sensors, microphones, and accelerometers) placed throughout the environment to perform the detailed observations needed for high-accuracy HAR. The difficulty of instrumenting an environment with these sensors makes current HAR systems impractical.

The goal of this project is to see whether recent advances in indoor localization make it possible to perform high-accuracy HAR using only a smartphone. Specifically, the project uses machine learning to combine indoor localization measurements, microphone recordings, and accelerometer data to detect a multitude of common human activities. Using a prototype designed to recognize eight common activities (typing, vacuuming, running the faucet, brushing teeth, making coffee, taking medicine, shaving, and cooking), this approach achieved an accuracy of 96.5%. These activities were chosen because they are difficult to detect with traditional smartphone HAR designs that lack fine-grained localization. Training a neural network using solely acceleration or audio information to recognize these activities achieves a far lower accuracy. This demonstrates that using a combination of acceleration, audio, and Wi-Fi Round Trip Time localization significantly improves upon current HAR models.

Generating Functional MRI (fMRI) Images via Eye-Tracking Classification for Artificial Brain Scans
Alay Shah
Plano West Senior School
Plano, Texas

Sponsor: Jerry Pruett

fMRI — or functional Magnetic Resonance Imaging — has a title as one of the most promising brain imaging & diagnostic tools used in modern hospital settings. fMRI has the capability to understand which parts of the brain are handling critical functions and which anatomical regions could be affected by brain disorders. Despite the fMRI's numerous benefits, it has serious issues with cost, portability, maintenance, and speed. As it turns out, though, the eyes may act as its own functional MRI. Eye movements also act as a window into our mind and a rich source of information about the brain's functions and health. These eye movements present themselves as a promising way to generate artificial fMRI images, but without an MRI machine. The developed tool uses an infrared camera sensor to deploy pupil-tracking and pattern-recognition algorithms that accurately identify abnormal eye sequences in response to stimuli and then uses a Generative Adversarial Network to create images that resemble fMRI scans. A unique set of visual animations and pictures are used to invoke specific emotions, cognitive

functions, and motor functions in patients, allowing the system to localize areas of brain activity. Clinical testing on human participants found that the tool could localize eye abnormalities within a short test and then proceed to generate a scan that resembled functional variances of real fMRI images with a 94% sensitivity and 96% specificity. With four unique patterns found over 40 participants, eye-tracking tools can deliver highly accurate & efficient brain scans.

The Effects of a Silica Coating on the Aggregation of Gold Nanoparticles

Paige Sherman (3rd place, Chemistry)
Hunter College High School
New York City, New York

Teacher: Philip Frankel

Mentor: Dr. Mrinalni Sharma, Hunter College High School

Gold nanoparticles (AuNPs) are a rapidly developing technology with applications in biosensorics, targeted drug delivery, cancer therapy, diagnostics, and purity testing. One of their properties that is often exploited in these applications is their tendency to aggregate in the presence of certain molecules, creating a color change. However, one problem scientists face when using AuNPs is that their aggregation is nonspecific and can be induced by many different molecules. In this study, AuNPs were coated in silica to try to control their aggregation in acidic and basic environments. Regular AuNPs and silica-coated AuNPs were prepared and placed in neutral, acidic, and basic environments, and changes in their light absorbance were measured with a spectrophotometer to determine if aggregation occurred. The absorbance spectrum of the silica-coated AuNPs showed significantly smaller changes in acidic and basic environments, demonstrating that the silica coating significantly reduced the aggregation of the AuNPs. Additionally, the silica-coated AuNPs showed slightly more aggregation over time in the acidic environment than in the basic one, demonstrating that unlike regular AuNPs, silica-coated AuNPs can be used to distinguish between acidic and basic environments. Because silica is biocompatible, the silica-coated AuNPs have the potential to be used for treatment *in vivo*, and their stability under conditions of varying pH indicates that they can be used in acidic or basic areas of the human body for improved drug delivery and photothermal cancer therapy, as well as the detection of other potentially dangerous molecules within an acidic or basic environment.

Pelagic Microplastic Concentrations in Yokosuka Based On Proximity to Tokyo

Austin Shinzato
Nile C. Kinnick High School
DoDEA Yokosuka, Japan

Sponsor: Ms. Kerry Stevens

Mentor: Gregory Murphy SRF

Plastic pollution in Japan is a growing issue, this excess of plastic degrades into microplastics which can cause long-term damage in an environment and for its inhabitants, even humans. These eroded plastics are known as microplastics which are defined as any plastic or synthetic fibers that range in the size of 1mm - 5mm. This study seeks to understand how the large urban city of Tokyo affects the microplastic concentrations in Yokosuka waters. The author chose to collect all samples with both a plankton net and babylegs net while specifically focusing on different areas of water around Yokosuka. The author hypothesized that the microplastic concentrations found in each location would slightly increase as their distance from Tokyo grew closer. Both qualitative and quantitative data taken by calculating the weight and concentration of the samples while also analyzing the overarching patterns observed from samples. From the experiment the author hoped to determine a significant difference in microplastic concentrations between locations closer to Tokyo. After applying a chi-square test with a p-value of .05 the author concluded that there was a significant difference between the locations that were closer to Tokyo and

the location furthest away. A theme present in the data was the presence and distribution of microplastics in Yokosuka waters.

Hyperglycemic conditions impair lung epithelial innate response to *Klebsiella pneumonia* infection

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Mentors: Deepa Talreja, Department of Biological Sciences, Oakland University, and Lytica Therapeutics
Satish K. Walia, PhD, Department of Biological Sciences, Oakland University

Bacterial pneumonia is a leading cause of mortality in adults with increased disease severity and complications in diabetic individuals. We hypothesize that hyperglycemic conditions impair pulmonary innate immune response to bacterial infection. In this study, we used human bronchial epithelial cells (16HBE and BEAS-2B cell lines) and challenged them with a standard strain of *Klebsiella pneumoniae (KP*) under normal (5mM, NG) and high (25 mM, HG) glucose conditions. Our data showed that *KP* grew more and proportionately caused more cell death under HG conditions. The qPCR and ELISA analyses revealed that *KP* infection increased the expression of inflammatory cytokines (IL-6, IL-8, & TNF-α) at both mRNA and protein levels in lung epithelial cells. However, the inflammatory response was higher under HG conditions which coincided with induced expression of Toll-like receptor 4 (TLR4), a key receptor involved in Gram-negative bacterial infection. The pharmacological inhibition of inflammatory signaling, NF-kB, MEK, and p38 attenuated *KP*-induced inflammatory response in NG but to less extent in HG cells. In addition to inflammatory cytokines, epithelial cells trigger the production of antimicrobial peptides (AMPs) to limit bacterial growth. Unexpectedly, we found that HG cells produced more AMPs (LL-37, HBD2, & HBD3) in response to *KP* infection. Finally, like ATCC strain, clinical isolates of *KP* evoked increased inflammatory response under HG conditions. Collectively, our study shows that hyperglycemic conditions dysregulate the innate response of lung epithelium by promoting an inflammatory milieu. These findings may assist in the development of therapeutic targets to treat bacterial infections in diabetic patients.

Predicting Early and High-Risk Parkinson's Disease Status via Boosted Machine Learning Techniques

Arjun Singh
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Warren, New Jersey

Mentor: Rashima Singh

Parkinson's Disease (PD) is one of the most prevalent neurodegenerative diseases globally. Diagnosing PD early is particularly difficult due to highly variable symptoms and the need for invasive procedures. To address this, I developed a streamlined, non-invasive decision justification system for the early diagnosis of PD. Early diagnosis will aid in the initiation of treatment to slow down neurodegenerative progression, significantly improving patient outcomes. I hypothesized that machine learning, an increasingly popular tool in computational biology, can be used to produce a highly accurate early PD status classifier. A dataset of speech features from patients with early untreated PD, REM behavior disorder (high-risk of developing PD) and healthy controls was acquired from the University of California, Irvine. One-hot encoding was used to normalize qualitative data. Six unique machine-learning-based classification models were developed, trained, and tested using this data to diagnose patients with the appropriate clinical classification. The highest-performing model was optimized via GridSearchCV, where four model hyperparameters were optimized over 320 combinations. This advanced classifier achieved a

96.15% accuracy and a 96.47% recall rate, suggesting that my hypothesis was correct. These results show that early PD detection and PD treatment can be significantly improved through machine learning.

Security or Insecurity Questions?
Hannah Skwarek, Emma Williams
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Millersville, Maryland

Teacher: Tammy Keatts

Are your essential accounts as protected as you think? Are you living under a false sense of online security? Cyber security is a major concern in the online age where protecting information is vital. Many accounts are secured with passcodes, which act as the key to unlock the information. If passcodes are the key, security questions are the hidden spare keys, which pose the greatest security risk. This project examines the effectiveness of common security questions in fulfilling their goal: to keep others out of an account but let the owner in. In order to determine whether security questions adequately protect accounts, we attempted to find volunteers' answers to the ten most common security questions using legal online resources. From the data collected, a few trends became clear. Most importantly, we discovered that not all questions are created equal. Answers to questions such as "What is your mother's maiden name?" that ask for non-private information that can be found on many public legal documents are easy to find online, and are therefore more susceptible to hacking. Questions such as "Where did you meet your spouse?" that ask for less documented information are harder to find and more secure. The data also indicated that younger individuals are more at risk for hacking compared to their older counterparts because their answers to the commonly asked security questions are more documented on various online platforms. Therefore, choose your questions wisely!

***Cure of Breast Cancer – Year 4*: First Discovery of New Target Therapy for Aggressive Hormonal Breast Cancer using Clinical Database and 3D Model**
Christine Song
Mayo High School
Rochester, Minnesota

Mentor: SeungBaek Lee, Mayo Clinic

The anti-estrogen tamoxifen is a highly effective hormonal therapy for hormonal (HR+) breast cancer patients. However, the estrogen receptor-negative, progesterone receptor–positive (ER- /PR+) subtype does not receive the benefits of tamoxifen. Therefore ER-/PR+ breast cancer have a poor clinical outcome, but drug development for ER-/PR+ breast cancer is not well studied. Here, we found that gene expression in ER-/PR+ HR+ breast cancer is positively related to triple negative breast cancer (TNBC) and not HR+ breast cancer using 4,319 breast cancer patients database. Especially, inflammation-related genes, USP1, CDC20 and CASP1, which are highly expressed in TNBC, are also upregulated in ER-/PR+ HR+ breast cancer. Suppression of USP1, CDC20 and CASP1 inhibit cancer cell growth and metastasis in ERα KO (ER-/PR+) cell lines. Interestingly, loss of ERα in HR+ cell lines is not responsive to tamoxifen, but highly sensitive to inflammation inhibitor, Ac-YVAD-CHO. In in vitro and ex vivo models, inflammation inhibitor specifically blocks ER-/PR+ tumor proliferation and migration. These findings suggest that the inflammation inhibitor might be the first potential target therapy for ER-/PR+ HR breast cancer patients.

Multimodal Deep-Learning Neural Networks based on a Multisensory Brain-Computer Interface to detect Mild Cognitive Impairment (MCI)
Saraswati Sridhar
Southwestern Educational Society

Mayaguez, Puerto Rico

Mentor: Evelyn Montalvo

Electroencephalogram signals are used to assess neurodegenerative diseases and develop sophisticated brain machine interfaces for rehabilitation and gaming. Here, a deep network based on sensorimotor data employs a subject-agnostic Bidirectional Long Short-Term Memory (BLSTM) Network is developed to generate powerful predictions using a variety of neuroimaging modalities and open-source patient data, as well as high-throughput computation, about the stage of cognitive deterioration a patient may be in, and to better detect neurodegeneration caused by illnesses like Alzheimer's.

Testing occurred with healthy subjects of age 20–40, 40–60, and >60, and mildly cognitive impaired subjects. Auditory, motor, visual and olfactory stimuli were presented during which Electroencephalogram/Electromyogram signals were recorded. A deep BLSTM Neural Network is trained with Principal Component features from evoked signals and patient data from open-source resources and assesses their corresponding pathways. The LaPlace and Fourier Transforms were performed to decompose multimodal neural data from MRI and fNIRS. Wavelet analysis is used to decompose evoked signals and calculate the band power of component frequency bands.

This deep learning system performs better than conventional deep neural networks in detecting Mild Cognitive Impairment (MCI). Most features studied peaked at the age range 40-60 and were lower for the MCI group than for any other group tested. The mean classification accuracy per age group declined from 91.93% to 56.64%, and is 32.45% for MCI subjects, particularly in the left visual stimuli and motor imagery tasks. The stage of deterioration present in the patient was detected with 95.7% accuracy using the transforms.

Connection ICU: A Novel Mobile Application to Prevent Delirium in the Intensive Care Unit

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Fort Collins, Colorado

Mentor: Courtney Gryskiewicz, MSN, RN, CNL, University of Northern Colorado

Patients with delirium suffer severe confusion, paranoia, hallucinations, and struggle to understand or pay attention to what is happening. The COVID-19 pandemic has worsened the already severe problem of delirium in Intensive Care Units (ICU). Family involvement in patient care is seen as a vital tool to manage delirium in ICUs. To facilitate family involvement in ICU patient care, a mobile application, Connection-ICU, was created. Connection-ICU comprises four sections: an educational information page for family members, an aide for providing reorientation messages, an ICU diary, and an area for photos and video messages. These sections were constructed based on research concerning the most effective ways to utilize family members in delirium care. The present study sought to assess whether it would be easy to use by the general population. Snowball sampling was used to recruit 133 participants to complete a usability survey after they interacted with the app. Supporting hypotheses, participants' ratings showed strong support for the app; 87.3% of participants agreed or strongly agreed that the app would be usable and help them increase involvement in care. Agreement was strong regardless of previous experience having a loved one in the ICU or with delirium. These results indicate that Connection ICU has potential to provide a feasible means for families to support loved ones during ICU delirium. While results are promising, more development of the app and further testing of both user opinions and implementation into real ICU delirium care is needed.

Dissolved Oxygen Augmentation Effects on the Hydroponic Cultivation of *Eruca sativa* in NFT System

Nicole Stover
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Jacksonville, Florida

Teacher: Todd Steele

Chlorosis is a common problem in the commercial growth of arugula in Nutrient Film Technique (NFT) systems and can be caused by nutrient or oxygen deficiencies. Building on conclusions from previous years, this project seeks to determine the impact of dissolved oxygen (DO) on chlorophyll levels, crop yield, and metabolic activity. Group A contained supersaturated DO, augmented by an emitter using electrolysis to produce nano-bubbles of oxygen. Group B, the control group, contained no added DO. Forty rockwool plugs with seedlings were used in each group, distributed in 4 growth channels of the hydroponic A-frame. Temperature, pH, DO, EC and chlorophyll were measured regularly throughout both trials to maintain the nutrient concentration and oxygen levels. At the end of experimentation, the mass of fresh foliage and dried roots were measured. At the end of Trial 2, neutral red, an ATP-dependent active transport stain, was used to evaluate nutrient uptake in the roots through microscopy and colorimetry. Plants in Group A had a greater foliage and root biomass, longer roots, higher chlorophyll levels, and less chlorosis when compared to Group B. Roots from Group A contained more secondary roots and root hairs, and had increased uptake of neutral red when compared to the control. Root length, chlorophyll levels, and the uptake of neutral red evidenced by colorimetry were all statistically significant ($p<0.05$). Augmentation of DO in commercial hydroponic systems should result in increased crop yield, overall profit for growers, and an increase in food supply for the community.

Digital IoT Geofencing for Anti-Wandering: A Machine Learning Approach

Edmund Sumpena
Westview High School
San Diego, California

Teacher: Domingo David

Wandering is a serious problem for people with dementia or developmental disabilities. This group includes patients of Alzheimer's disease, autism, Down syndrome, or other neurological disorders involving memory loss. Wandering may lead to serious injury or fatality. Existing anti-wandering approaches are often reactive in nature, involving searching for patients after they have wandered away. In most cases, they require costly and manual police intervention and rescue operations.

To mitigate the negative and possibly tragic consequences of wandering, early detection of patients leaving their designated safe zone is crucial. To achieve the goal, this research is about designing preventive geofencing technology that complements existing solutions by taking a proactive approach. The technology, termed WanderGuardian, adopts a novel, flexible, indoor-compatible, and privacy-protecting machine learning algorithm. With this system, a caregiver sets up a predefined digital safe zone using an Internet of Things (IoT) device or phone. In its training phase, the system learns environmental signals as "signatures" and improves in-out detection over time by adapting to its dynamic surroundings. It analyzes the signatures to determine if the patient is within the safe zone using a regressive classification model. The patient is tagged with a Bluetooth low energy beacon, allowing the system to continue monitoring the patient's location even when the patient is not carrying the phone. I have implemented the system in Android and conducted extensive experiments to validate the design and performance of WanderGuardian. Results confirm the algorithm's high adaptivity, accuracy, and power efficiency in a wide range of environments.

Functionalized Polylactide Filament for Additive Manufacturing

Suvin Sundararajan (2nd place, Chemistry)
Westfield High School
Westfield, Massachusetts

Supervisor: Elizabeth Stubbs, Department of Polymer Science and Engineering, University of Massachusetts

This project explores the polymer manufacturing process of new filament for fused deposition modeling (FDM). The purpose was to enhance the flame-retardance properties of polylactide, an industry standard filament, so as to be viable for commercial applications involving additive manufacturing.

Polymer-based filament was synthesized on a preparative scale with polylactide (PLA) and targeted loadings of deoxybenzoin (DBPE), a novel non-halogenated polyester for flame retardance. To screen the efficacy of the chosen additive, a four-step process was conducted which consisted of a.) synthesizing the deoxybenzoin, b.) batch mixing and compression molding of additives c.) extruding filament at a constant rate using a self-developed robotic puller, and d.) printing the filament on an FDM printer.

Properties of this polymer blend were compared with commercial benchmarks for flame- retardance in polymers to assess real world applications. The composition was characterized by FT-IR, differential scanning calorimetry (DSC), rheological tests, and optical microscopy. Flammability was tested on printed samples using microscale combustion calorimetry (MCC), and thermogravimetric analysis (TGA).

The final blend used a 3.8% loading of flame retardant, which is significantly lower than the 10-50% loading of flame retardants used in commercial applications. MCC indicated that the heat release capacity of the deoxybenzoin blend was improved by 20% and charring was increased by 4x compared to standard PLA, with negligible tradeoffs in other properties. With a yield strength of 50 mPa, this blend performs higher overall compared to PLA and other polymers used in 3D printing.

Impervious Surfaces and Stream Health: A Study Using Machine Learning and Multivariate Statistics

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Teacher/Mentor: Dr. Kathleen Morrow

Impervious surface area is projected to triple within the next three decades as a direct consequence of proliferating urbanization. Impervious surfaces, which are man-made architectural features that prevent absorption of water such as buildings and roads, play a profound role in affecting surface runoff and physio-chemical properties of stream systems. Thus, quantifying and studying impervious surfaces is crucial to understanding the breadth of anthropogenic influence. However, current methods of quantifying impervious surfaces require complex procedures, expensive software, and experienced personnel. As an alternative, we designed a novel machine learning approach that utilizes Google Maps and a K-Nearest-Neighbors (KNN) supervised algorithm to quantify the percentage of impervious surfaces (PoIS) surrounding 21 urban stream sites in Fairfax County, VA. Non-metric Multidimensional Scaling (nMDS) was conducted to analyze the relationship between PoIS and 10 water quality parameters based on the Bray (Sorenson) distance matrix. Permutational Multivariate Analysis of Variance (PERMANOVA) was used to detect the strength of dissimilarities among stream sites. Our research demonstrates that impervious surfaces are negatively correlated with the ecological health of Fairfax County streams. In addition,

the developed machine learning algorithm used to quantify PoIS may serve as a useful tool to identify high risk streams, or areas that should be monitored. The algorithm will help both managers and general public better understand our urban stream environment, serving as a foundation for cost-effective water-resource management.

The effect of natural remedies for epilepsy on the recovery time of *Caenorhabditis elegans* being electroshocked in order to induce a seizure

Simran Tippabhatla
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Columbia, South Carolina

Teacher: Lindsey Rega

Antiepileptic drugs are known to cause unwanted side effects such as nausea and vomiting. In order to prevent these side effects, the use of natural remedies has been considered. It was hypothesized that, "After exposure to Vitamin D3 extract, *C. elegans* will recover faster from electric shock than they will after consuming chamomile or not consuming a remedy at all." Three groups of *Caenorhabditis elegans* were fed and raised using *Escherichia coli*. One group was left untreated, one group had Vitamin D extract on the surface of the agar plate, and the third group had chamomile extract on the surface of the agar plate. After 48 hours, M9 saline solution was poured into each plate and an electrical shock was run through it. Thirty worms from each group were observed individually to record how long it took for them to recover from the shock. After data from the three groups were analyzed, it was found that the control had an average recovery time of 204.532 seconds, the Vitamin D group had an average recovery time of 36.67 seconds, and the chamomile group had an average recovery time of 84.76 seconds. A one way ANOVA test at alpha = 0.05 was conducted to conclude that the average recovery time of the groups were statistically significant, as $p<0.05$. The data suggested that Vitamin D allowed the *Caenorhabditis elegans* to recover fastest from the electric shock, making it most effective in the reduction of simulated seizure response.

Predicting Blood Brain Barrier Permeability of Neural Drugs: a Novel Approach Using SMILES and Machine Learning

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Teacher: Iris Thompson

Long periods of development, difficulty of conducting clinical trials due to the complexity of the brain, and the lack of efficient drug delivery technology result in a lower number of available neural drugs. Machine learning algorithms use past data inputs to build a predictive model that determines future outputs. The objective of this project was to construct a random forest classifier with a minimized number of chemical features that would be able to predict the permeability of a neural drug more than the threshold prediction score of 0.92. Using a correlation matrix, some chemical features were discarded and nineteen final molecular descriptors were used. The data was split into testing and training sets (8:2 ratio), and random forest classifiers with 10,100,500, and 1000 estimators were created. At 10 estimators, the prediction score was the greatest at 0.96 which is greater than the current prediction value. An accuracy score of 0.95, recall score of 0.93, precision score of 0.81, and a specificity score of 0.95 were recorded, supporting the initial hypothesis. An user interface allowing a parameter of SMILES and the nineteen chemical features was created. Limitations of this project include a relatively small(1500) neural drug dataset. Future research includes expanding to predict the drug delivery mechanism of permeable neural drugs. A current application of this program is that it can be an inexpensive approach for neural drug research.

Comparing the Biodegradability of Petroleum-based Plastic with a Novel, Sustainable Bio-plastic Alternative

Lana Van Note (3rd place, Environmental Science)

Marine Academy of Technology and Environmental Science
Manahawkin, New Jersey

Teacher: John Wnek

The convenience and affordability of single-use plastic products makes them an attractive option for consumers. The toxic constituents of these traditional plastics, however, are known to cause a variety of health issues in thousands of species. These environmental hazards, along with the issue of white plastic and microplastic pollution, causes increased interest in biodegradable alternatives to petroleum-based hydrocarbons. In this research, a novel bioplastic inclusive of bamboo tannins and chitosan is selected from more than 60 trial formula variations based on resulting strength, fatigue, and transparency attributes. The biodegradability of the finalized bioplastic is compared to that of conventional polyethylene, in addition to investigating its solubility and water absorbance. Biodegradation rates of the bio-based plastic exceeded that of the petroleum-based formula, as determined with Fourier Transform Infrared Spectroscopy (FTIRATR) analysis. The behavior of the experimental product in water deviated from the initial hypothesis, with substantial weight increase of approximately 193% after 60 minutes. A cost analysis displayed a difference of $0.0016 between the two products, with the natural additives of the experimental being more expensive. This research displays the potential of a legitimate, fully biodegradable plastic alternative to current marketplace bioplastics.

Evaluation of Four Materials for Growing Aquatic Algae to Produce Biofuel

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Bowling Green, Virginia
King George High School
King George, Virginia

Teacher: Kevin Goff, Chesapeake Bay Governor's School

In this study, four different material plates (wood, concrete, aluminum, and vinyl) were placed in the Potomac River to see what material would grow algae the fastest to make biofuel. The materials were placed on top of floating oyster bags that were located off the Potomac's shore in sheltered Hex Boxes. The data was recorded over four weeks by using a percent coverage grid. Then the weight of the plates was measured to find the total wet and dry algae mass, and the algae was then analyzed chemically for lipid content. The results show that wood and concrete had the quickest recruitment of algae, but vinyl had the highest percentage of energy-rich lipids, which are necessary for biofuel. Since vinyl had the least algae mass, but produced the most lipids, this makes vinyl the optimal material to use when growing algae for lipid use.

Stable Isotope Analysis of Maine-Caught Striped Bass (*Morone saxatilis*) Otoliths as a Means of Determining Natal Origin

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Falmouth, Maine

Mentor: Zachary Whitener, Gulf of Maine Research Institute

This study conducted stable oxygen isotope analyses of striped bass (Morone saxatilis) otoliths to determine the natal origin of a Maine-caught fish cohort. During the first stage of this study, 15 striped bass from the Kennebec River were analyzed for stable oxygen isotope ratios (18O/16O or δ18O). A native Maine striped bass isotope range was thereby established. 72 Maine-caught striped bass were then analyzed for δ18O. δ18O values for Maine-caught bass were compared against the previously established native Maine range, as well as against white perch isotopic data sampled from the Chesapeake Bay. White perch were selected as a proxy for striped bass, as no comparable striped bass data was available. Chesapeake Bay isotopic data was selected as these waters serve as the major nursery for Atlantic striped bass. 4 of 72 (5.6%) Maine-caught bass had δ18O values consistent with a Maine natal origin (Maine-based spawning ground). 27 of 72 (37.5%) Maine-caught bass had δ18O values consistent with a Chesapeake Bay origin. 41 of 72 (56.9%) Maine-caught bass were of indeterminate origin. A t-test was performed to evaluate similarities between the native and Maine-caught populations. The results suggest that the populations are significantly different ($P < 0.01$). Stable oxygen isotope analysis appears to be an effective method of establishing the natal origin of Maine-caught striped bass. This origin data can be used to focus and refine striped bass conservation policy, as well as to assess the health of recently restored historic Maine spawning grounds.

From Data Clouds to Analytical Functions: Understand Neural Networks Through Artificial Intelligence and Machine Learning

Ethan Wang
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Mequon, Wisconsin

Teacher: Jeff Patterson

Experiments and data analysis have been crucial to the discovery of many fundamental laws in science and engineering. For simple one or two variable functions, MATLAB has a curve fitting toolbox which can correctly predict the relationships between inputs and outputs; however, more complex equations with multiple variables still have no reliable approach to extract a function from given data. Neural networks are excellent at making predictions, but they lack the ability to produce an analytical function from data. This study attempts to use a neural network based classifier to study the differences across different neural networks. Through this method, a neural network is trained from experimental data and then a pre-trained classifier sorts it into one of many potential functions. In a feasibility test, the pre-trained classifier was able to identify three variable functions with a 90% accuracy rate. When used in experimental science, this approach can give researchers the ability to reliably draw concrete analytical functions from experimental data.

Evaluation of Metabolic Hormone Therapy Amyloid-beta Processing in Alzheimer's Disease- Modeled Mice

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Hathaway Brown School
Shaker Heights, Ohio

Teacher: Dr. Crystal Miller

Mentors: Rachel Corrigan and Dr. Gemma Casadesus, Kent State University

Metabolic dysfunctions such as obesity and Type II Diabetes have been found to be one of the largest risk factors for developing late-onset Alzheimer's disease (AD). Amylin, a hormone co-secreted with insulin, helps to regulates blood glucose levels. Outside of peripheral metabolism regulation, amylin may also have other homeostatic functions in the brain. It has been previously shown that Pramlintide (PRAM), an analog of amylin, reduces amyloid-beta (Aβ) plaque pathology in the hippocampus and cortex of AD-modeled mice. However, it is largely unknown if the neuroprotective effects of PRAM therapy are due to the activation of CNS amylin receptors (AMYR) or due its benefits on metabolic function in the periphery. To address this, we used Western blotting to determine

changes in levels of proteins involved in Aβ regulation in brains of APP/PS1 AD-modeled and WT mice under PRAM-treatment and under PRAM while blocking the AMYR centrally with an inhibitor (AC187). We hypothesized that PRAM would regulate Aβ processing aspects that would be blocked by AMYR inhibition. Results thus far show that PRAM may work centrally to increase α-secretase and lower levels of Aβ. We have also determined that PRAM benefits are unlikely to be related to its ability to regulate degradation of amyloid beta.

The Effects of Light Color and Temperature on Stomatal Geometry in Boston Ferns (Nephrolepis exaltata)

Kesara Wein
State College Area High School
State College, Pennsylvania

Supervisor: D. Rosensteel

An essential chemical process that occurs on earth is transpiration. Not only is transpiration vital for gas exchange and the health of plants, but is also responsible for initiating photosynthesis. Transpiration relies on stomata, small pores on the undersides of leaves and due to this, stomata serve as a crucial component in organisms. As a result of their necessity, further inquiry of these stomata, the guard cells that they consist of, and their behavior in various conditions is burgeoning. This study examines the geometry of stomata in response to environmental conditions of light color and temperature being altered. The length and area of the stomatal aperture and guard cells were measured with ImageJ Fiji software. Using StatCrunch, a One-way ANOVA test was performed, and the resulting data was significant. The general trend observed during the trials was that stomata in control conditions had the shortest aperture and guard cell length as well as least area covered by guard cells and apertures, while the experimental conditions had reasonably larger of both. The significance of the findings as well as the trends, exhibit that light color and temperature conditions have an effect on stomata and may play a greater role in transpiration and plant health.

Utilization of Sugarcane Cellulose to Create a Composite Concrete

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This research investigates a sustainable concrete reinforcement material produced from the byproduct of sugar production. This byproduct, known as sugarcane bagasse, was obtained and processed through the use of Na_2CO_3 (Sodium Carbonate) to separate organic material and allow for easier separation. After 2 processing steps using Na_2CO_3 and Water, the sugarcane bagasse was dried and separated into individual fiber strands. These fibers were incorporated into a concrete mixture in differing volumetric concentrations, ranging from 0%(control) up to 15% with 5% increments in between. Each concrete was poured into molds, and the resulting 40 test specimens were left to cure. These specimens were subject to a tensile stress test after 7 & 28 days of curing, unitizing a Structural Stress Analyzer (SSA). Through precise computational measurements, the SSA determined the force it applied to a sample and how much that sample had deformed. It was discovered that samples with a fiber content of 10%/unit volume were 11.4% stronger on average than the control samples (0% fiber/unit volume). In addition to their strength, the 10% samples mitigated phenomena such as concrete spalling and crumbling. These preliminary results suggest that if such a fiber were deployed to developing nations, structures would become safer, and disaster would become less deadly.

Investigation of bacterial gene transcription from promoters with proximal i-motifs and G-quadruplexes

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Sponsor: Dr. Jay Meyers

i-Motifs and G-quadruplexes are unusual DNA secondary structures that have been implicated as regulatory elements for eukaryotic gene expression. i-Motifs are intercalated ladder formations made up by intrastrand C-C base pairing, and G-quadruplexes are stacked intrastrand G-G base pairings. Research on these structures is continuing but some new studies suggest existing therapeutic small molecules may interfere with their formation and subsequent stability. The purpose of this investigation was to observe the effects of the known antitumor drug mitoxantrone's potential interactions with these structures on gene transcription. I inserted four i-motif- and G-quadruplex-forming sequences 17 base pairs upstream of the T7 promoter R0085. This promoter is within a transcription cassette for Green Fluorescent Protein. Differences in gene expression were measured with fluorometry both *in-vivo* and *in-vitro. In-vivo*, increases in gene expression were observed for nearly all promoters with the addition of mitoxantrone. However, in-vitro experiments displayed a consistent decrease in gene expression for all promoters with the G-quadruplex on template strand. Additional measurements of UV spectroscopy revealed increasing stability of the G-quadruplex with the increasing concentration of mitoxantrone. Implications of this research suggest mitoxantrone might affect and further alter gene expression by promoters downstream of sequences containing G-quadruplexes on the template strand, such as RET and BCL-2.

A Machine Learning Approach to Optimize CRISPR-Cas13d RNA Targeting as an Antiviral Therapeutics

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RNA viruses such as coronavirus pose serious threat to human health. A recently discovered CRISPR-Cas13d system can cleave target RNAs with relatively high efficiency, showing considerable potential to treat RNA viruses. However, one major challenge for scalable CRISPR-Cas13d therapy is the absence of quick and accurate method to select desirable guide RNA (gRNA), which is an essential component that determines efficiency and specificity of Cas13d therapy. To solve this problem, this study created a CRISPR-Cas13d prediction tool based on convolutional neural network (CNN) machine learning to accurately select potent gRNAs in silico.

Firstly, this study developed a CNN model trained on Cas13d gRNA dataset from published experimental results and reached a high performance. To further test its clinical application, this Cas13d prediction tool was applied to select potent gRNAs targeting SARS-CoV-2 (Covid-19 coronavirus), where predicted gRNAs were compared with ground-truth experimental results and yielded an accuracy of 90.4%, out-performing the state-of-the-art prediction tool by 20.1%. In addition, the entire prediction process for coronavirus was within 3 minutes. This tool's high rapidity and accuracy on real world application proved its ability to develop efficient antiviral Cas13d therapies.

This study was the first attempt that used machine learning on Cas13d gRNA selection, reaching a competitive performance. This tool would provide a solution to the fast mutation rate of the RNA viruses by accurately and quickly predicting new gRNAs specifically targeting the mutant viruses. Furthermore, this study identified the best machine learning configuration that could be applied to other CRISPR-based gene therapeutics.

A Novel Epidemiological Approach to Exploring the Implications of Social Determinants of Health on COVID-19 Spread: A Call to Action for Health Equity

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Healthcare disparities predominantly affect socially vulnerable populations nationally and internationally. During the COVID-19 pandemic, social determinants of health (SDOHs) have played a significant role in COVID-19 incidence and fatality. However, the impacts of general social vulnerability and government intervention on COVID-19 outcomes are not well understood. Here the correlation between the twin pandemics of adverse SDOHs and COVID-19 and the efficacy of public health intervention in mitigating this double hit on vulnerable communities are shown. Utilizing the United States Centers for Disease Control and Prevention's Social Vulnerability Index (SVI), the New York City counties were categorized into three vulnerability cohorts. Data on daily cases, deaths, and hospitalization by county reported by the New York City Department of Health and Mental Hygiene for the months of March and May 2020 were analyzed and a Susceptible-Infected-Recovered-Deceased (SIRD) model was fitted to them. These results demonstrate that more socially vulnerable populations appear to experience greater COVID-19 cases and mortalities and that specific city, state, or US federal government intervention correlated with reduced disparities in COVID-19 outcomes. Moreover, moderately vulnerable communities observed the greatest rate of COVID-19 cases and deaths and highly vulnerable communities exhibited the greatest cumulative number of COVID-19 cases and deaths. These findings identify potential public health interventions that can increase health equity in various settings. In addition, the SVI-Stratified SIRD model technique offers a more comprehensive methodology for exploring the role of social vulnerability on communicable disease spread and can be applied to future disease outbreaks.

A Highly Selective and Sensitive Novel Biosensor Capable of Quantifying and Monitoring a Clotting Factor Elevated in Severe COVID-19 Cases

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Mentor: Ji Hoon Lee, Luminescent MD, LLC

In order to prevent blood clots in severe COVID-19 cases, a highly selective and sensitive biosensor capable of quantifying trace levels of thrombin using the combination of a single stranded DNA (ssDNA) aptamer (TBA) and a complementary probe of thrombin was developed. TBA rapidly binds with thrombin in the presence of the complementary probe, whereas it binds with the complementary probe to form a double stranded DNA (dsDNA) in the absence of thrombin. SFC (or Chamel) green, luminescent dyes, inserted into dsDNA cannot emit light in a 1,1'-oxalyldiimidazole chemiluminescence (ODI-CL) reaction, whereas they emit bright light in the presence of G-quadruplex and the complementary probe. Thus, the brightness of the light from the biosensor with ODI-CL detection was proportionally enhanced with the increase of thrombin in a sample due to the increase of G-quadruplex and reduction of dsDNA. The limit of detection (LOD) of the biosensor operated with a good linear calibration curve (0.01-0.32 U/ml) was as low as 0.003 U/ml. Also, the biosensor quantified trace levels of thrombin with good accuracy, precision, and reliability within a statistically acceptable error range. In conclusion, the principle and concept applied for the first time to develop the biosensor can be used in various research fields for the diagnoses of human diseases and the monitoring of toxic materials existing in food and nature.

Reconstructing Rooted Trees from Their Strict Order Quasisymmetric Functions

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Graphs are mathematical objects with many theoretical and practical applications, especially in computer science, where computer networks and many data structures can be represented by graphs. There is particular interest in finding a fast algorithm to check whether two graphs are equivalent, or isomorphic. A positive resolution to this problem would revolutionize graph theory: showing that isomorphism is easily computable would directly imply numerous other computability results about graphs, leading to simpler algorithms and significant efficiency improvements in computer vision, database searching, and other computational applications of graph theory.

One approach to resolving this problem is to study graph invariants, which can be thought of as Google Lens readings: they can quickly produce partial information about a graph. Thus, calculating graph invariants can greatly reduce the work required to check graph isomorphism. In this research, I studied a graph invariant called the strict order quasisymmetric function (SOQF), a recent variant of Richard Stanley's widely studied chromatic symmetric function. I tackled the SOQF from a computational perspective, devising an algorithm to explicitly reconstruct graphs called rooted trees from the SOQF. The algorithm provides the first combinatorial proof that the SOQF can distinguish all rooted trees. It also tracks down a finite set of representative terms for each rooted tree, making it computationally feasible to compare rooted trees using their SOQFs. This new technique can be applied to a wide variety of chromatic symmetric functions, opening new theoretical approaches and computational applications for numerous graph isomorphism problems.