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# 2026 High School Student Abstracts

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**How Ballot Order Can Affect Voter Behavior**
Bradley Forcier

Alphabetical ballot order may influence voters into voting for a candidate simply because their name is higher up on the ballot. The purpose of this experiment was to test the effect ballot order can have on elections. The hypothesis was that, if a voter is presented with an alphabetically-ordered ballot, then they are more likely to vote for candidates with lower names alphabetically because they are ordered higher up on the ballot. A survey was created containing a mock 2028 presidential ballot, political background questions, and demographic questions. The mock ballot had four variations: alphabetically ordered without a biography, randomly ordered without a biography, alphabetical with a biography, and random with a biography. Results showed that, although there were some trends indicating a negative correlation between alphabetical position and vote share, there was little variation between the random and alphabetical ballots. Ultimately, this experiment was not able to sufficiently prove the hypothesis, although there was some evidence in favor of it, and more research is warranted into the hypothesis to allow for a more generalized conclusion.

**The Sweet Influence : How Labels Shape Our Perception on Dessert Taste**

Aaliyah Molina, Anaje  Rodriguez

The problem being investigated today is whether people can distinguish sweet, healthier, or natural among blind-coded dessert samples. Our research question is "the perception of sweetness on store bought desserts and how you identify what is in your food. " In order to conduct our research, we set up a table with four different crushed cookie samples and pulled 10 different participants to taste test. After that they took a survey about their tastings and what cookie they thought were the most healthy, natural, and had less sugar. The study concluded that people might not be able to identify what is in their food only by taste perception, disapproving our hypothesis, if people taste blind-coded dessert samples they should be able to distinguish the sample that's more healthy, and the sample that is natural.

**"BehavioSync": Matricaria chamomilla Extract Attenuates Depressive-like Behaviors and Neurocognitive Impairment in Zebrafish via Neuroinflammatory Modulation**

Cindy Ren

An estimated 85%~94% of patients with depressive disorders experience cognitive impairments such as memory decline, and these symptoms persist after remission in 39%~44% of cases. This is partially because conventional treatments inadequately address shared pathological mechanisms such as chronic neuroinflammation, while remaining costly with significant side effects. This study investigates Matricaria chamomilla (chamomile) as a plant-based alternative for alleviating depressive-like symptoms and neurocognitive impairment in a zebrafish model. The pharmaceutical viability of chamomile extract was analyzed using high-performance liquid chromatography (HPLC) and in silico modeling. Reserpine-induced zebrafish, stratified by sex, were treated with 5, 10, and 20mg/L of chamomile extract or controls. The behavioral outcomes were measured using the Novel Tank Test, Light/Dark Preference Test, and Y-maze Test, supported by a novel deep-learning-based automated tracking system, "BehavioSync," that achieved >90% accuracy and 500% increase in efficiency compared with existing methods. Molecular effects were assessed by RT-qPCR analysis of HTR1AA, HTR1AB, TNFα, and BDNF expression normalized to actin. Results showed that chamomile treatment improved depressive-like behaviors and neurocognitive impairments, following an inverted U-shaped dose-response pattern with optimal efficacy at 10mg/L. Identification of bioactive phenolic compounds further supported its therapeutic potential. RT-qPCR findings indicated downregulation of TNFα and upregulation of HTR1AA/AB and BDNF, providing evidence for modulation of TNFα-linked neuroinflammatory pathways. Notably, female zebrafish appeared more sensitive to treatments and overdose effects. Overall, these findings support chamomile as a promising therapeutic option for depression and memory impairment, while establishing a scalable behavioral tracking platform and experimental framework for future drug discovery studies.

Keywords: Matricaria chamomilla; depression; neurocognitive impairment; neuroinflammation; TNFα; deep learning

Belchertown High

**Mindset Over Mistakes: Measuring the Impact of Mindset Training on Gymnasts' Confidence and Performance**

Elise Roggie

Competitive gymnastics requires flawless execution, placing significant psychological demands on young athletes who often lack the necessary tools to handle this pressure. This study aimed to examine the impact of a four-week mindset workshop on self-reported confidence and performance in adolescent gymnasts. It was hypothesized that after participants undergo a four-week mindset workshop, there would be an increase in confidence and performance. Ten participants completed a pre-workshop questionnaire consisting of 15 1-5 Likert scale statements. Each workshop covered different topics relating to mindset. Session topics included the importance of growth mindset, reframing negative thoughts, overcoming mental blocks using tools like visualization, and setting appropriate and relevant goals. The event competition scores for ten participants were used to assess changes in performance before and after the workshop. Results demonstrated an increase in confidence reported on the questionnaire from prior to the workshop ($M=3.69$, $SD=0.27$, $n=10$) to after the workshop ($M=4.15$, $SD=0.29$, $n=9$). An independent t-test indicated a statistically significant increase in confidence after the intervention, $t(17)=3.65$, $p<.002$, with a large effect size (Cohen's $d=1.68$). Mean event scores remained constant between pre-intervention and post-intervention competitions ($M=8.73$, $n=10$). A paired sample t-test showed no statistically significant difference in performance scores ($p > .96$). Despite this, 70% of participants showed improved or maintained performance during the workshop. These findings suggest that even short-term mindset education can improve confidence in young athletes, potentially leading to an increase in performance quality.

**The Effects of Music in The Brain: Musicians and Non-Musicians**

Geovanni Tolentino

The purpose of this project was to see how music can affect a person's ability to focus on music whether they're a musician or not, by measuring how differently their brainwaves alpha, beta and theta activity levels react to the music. This could help with further understanding how the brain works with music and if it works differently depending on the time spent studying and playing music. For the procedure the muse headband was put on participants as well as headphones for the music. The variables of the study were: Musicians and Non-Musicians, being the independent variables; Alpha Beta and Theta being the dependent variables. In this project what was classified as a musician was someone with 4 years of experience with playing an instrument. There were 4 participants in total. They were put into groups of two. The Musicians and non musicians. In each group there was an adult and a student. After analyzing the data of all 4 participants brainwaves, there was no significant difference that showed the musicians had more activity.Data was analyzed with Mind Monitor app charts and the hypothesis of "If the person is a musician, then the alpha beta and theta brainwaves will have more activity than the person who's not a musician"  was disapproved given that the data was not significantly different between musicians and non-musicians. One thing that was noticed was that the students had more activity in their brainwaves compared to the adults. In the end the hypothesis was disproved because of the fact the musicians brainwaves weren't more active.

**Protect Against Toxic Waste**

Alisa Catulle

Tooth decay is a widespread problem, with cavities playing a vital part in all of it. This experiment was to investigate how different types of candy affect enamel erosion and whether fluoride toothpaste helped reduce the erosion. Eggshells were used to mimic enamel; 22 samples, weighing 2g each. Each sample was exposed to various types of candy, all weighing 5 g each, with different acid and sugar levels. 11 of the samples had fluoride toothpaste applied to them before being exposed. To determine the amount of erosion that occurred, the eggshells were weighed before and after the experiment, and the difference in mass was shown to be the erosion. However, weight wasn't the only variable needed, as visible changes and pH levels were crucial. Samples whose pH increased more during the experiment showed to have more detrimental changes, usually having a lower final mass and harsh visual changes. Visual changes seen throughout the experiment included eggshell color, texture changes, and the fragility of the eggshell. These factors helped determine which sample had gone through the most erosion. The results showed that the greatest erosion occurred in the sample exposed to sour candy without fluoride toothpaste. These findings highlighted a pattern: the higher the acid and sugar levels are in candy, the more erosion the enamel faces, and how fluoride toothpaste can help limit the effects.

Deerfield Academy

**POEM-KD: Persona-Oriented Efficient Model for Poetry Rewriting with Knowledge Distillation**

Katie Kim

Poetry rewriting requires more than fluent paraphrasing; it must preserve the semantic content of the source poem while reproducing the target author's persona, including diction, cadence, punctuation habits, and symbolic tone. Existing controllable text-generation methods often maintain surface meaning but fail to sustain a convincing poetic voice, while standard knowledge distillation and compression methods improve efficiency at the cost of stylistic depth. To address this gap, we propose POEM-KD, a Persona-Oriented Efficient Model for Poetry Rewriting with Knowledge Distillation. POEM-KD employs a hierarchical Teacher–Assistant–Student framework in which a large Teacher model transfers stylistic and semantic knowledge to an intermediate Assistant and then to a lightweight Student model. The Student is trained with a multi-objective loss that combines cross-entropy supervision, knowledge distillation, semantic preservation, and persona fidelity. Public-domain English poems collected from Wikisource and Project Gutenberg are used for training and in-distribution evaluation, while a separate test-only local set of self-authored poems is used to examine out-of-distribution generalization. Experimental results show that POEM-KD achieves a semantic similarity score of 0.91 and a persona fidelity score of 0.88, outperforming baseline systems while reducing inference latency to 64 ms through quantization, pruning, and adapter-based tuning. Qualitative analysis further indicates that the proposed framework produces more globally coherent persona transfer, rather than isolated stylistic markers at the line level. These findings suggest that hierarchical distillation, when paired with meaning- and persona-aware objectives, provides an effective and scalable framework for efficient computational literary generation across both in-distribution and out-of-distribution poetry rewriting settings for practical deployment.

Keywords: poetry rewriting, persona fidelity, knowledge distillation, style transfer, computational literature

Discovery Polytech Early College High School

**Do Immersive VR Scenarios Reveal a Mismatch Between Perceived Stress and Physiological Response**

Dayneris Rodriguez, Misael Mercado

The purpose of this study is to investigate if the body and mind align with what people are feeling. Sometimes when someone is calm, their heart rate and brain activity can show how they actually feel. For example, how stressed they are. With thus we wanted to see if people's perception of stress actually matches their body's response. The participants would experience two different VR scenarios, one that would be considered “chaotic” and the other that would be considered “calm.” Before these scenarios we would record baseline, throughout this we would measure their brain activity and heart rate. After each scenario and before, the participants would complete surveys about their perceived stress and calmness. The independent variables that we would manipulate were the 3 different conditions: baseline, stressful, and calm scenario. The dependent variables would be the participants' perceived stress, their EEG alpha and beta activity, and their heart rate. Each participant completed one trial of the three separate conditions. As a result, there were some mismatches between perceived stress and their physiological responses. During the stress scenario, the heart rate was able to increase more than Beta activity. In some trials, beta activity decreased instead. Our results ended up partially supporting our hypothesis that there will be a mismatch between perceived stress and physiological response. The physiological response won't always increase on both ends, such as EEG activity won't always increase when heart rate does. This is important as it shows that stress cannot just be measured on a limited number of factors, but multiple, showing that the mind and body may not always respond in the same way you would believe it does.

Rivers School

**Distinguishing AI-Generated Faces Through Geometric Measurement and Statistical Analysis in Excel**

Maylea Harris, Zimon Li

This study investigates whether systematic geometric differences exist between AI-generated and real human faces that can be detected using accessible measurement tools rather than complex programming. Using ImageJ software, we manually measured six key facial distances on 200 images—100 real faces from the CelebA dataset and 100 AI-generated faces from ThisPersonDoesNotExist.com. For each image, we calculated three facial proportion ratios: interocular distance to face width, nose-to-mouth distance to mouth-to-chin distance, and mouth width to nose width. These ratios were analyzed using Microsoft Excel's statistical functions.

Statistical analysis revealed significant differences between the two groups ($p < 0.001$). The nose-to-mouth to mouth-to-chin ratio also differed significantly between groups (two-sample t-test, $t(198) = 3.42$, $p = 0.001$). Using these findings, we developed a simple linear discriminant model in Excel based on threshold values for the three ratios.

These results demonstrate that despite the perceptual realism of StyleGAN-generated faces, they contain detectable geometric irregularities that can be identified through systematic manual measurement and basic statistical analysis. This accessible methodology provides an alternative to "black box" deep learning approaches for digital forensics and offers quantitative evidence for the subtle ways in which AI-generated faces may trigger the "uncanny valley" effect. The success of this approach suggests that fundamental geometric principles remain a powerful tool for distinguishing between biological and synthetic faces, even as AI generation capabilities advance.

Keywords: AI-generated faces, geometric analysis, facial proportions, ImageJ, Excel statistics, digital forensics, uncanny valley, manual measurement.

Phillips Academy

**SmartBlink: Real-Time AI-Driven Adaptive Pedestrian Traffic System for Enhancing Perceived Pedestrian Safety and Traffic Efficiency**

Yaejoon Jung

Pedestrian-vehicle conflict at intersections is a major safety challenge, as conventional fixed-time traffic signals do not adapt to real-time pedestrian crossing behavior and drivers often fail to yield. Conventional traffic infrastructure has historically been designed to prioritize traffic flow, often treating pedestrian movement as a secondary constraint and overlooking the behavioral interactions between pedestrians and drivers that shape safety outcomes (Litman, 2022; Appleyard, 1981). This study presents SmartBlink, the first adaptive traffic light system to simultaneously integrate individual pedestrian mobility and vehicle behavior into a single closed-loop coordination system for enhancing pedestrian and perceived pedestrian safety at intersections. The system integrates 1) real-time pedestrian speed detection through optimized YOLOv11, 2) perspective-corrected algorithm for accurate distance and speed estimation for crossing-time prediction, 3) approaching driver behavior including deceleration and braking, and 4) customized alert to pedestrians and drivers at risk situations via mobile app, while giving minimal impact to overall traffic flow. SmartBlink's pedestrian detection system demonstrated strong system robustness across lighting conditions and intersection widths. It accurately detected real-time pedestrian speed to calculate the amount of extra time needed for individuals to cross in real-life testing conditions, providing extended time based on the real-time speed of the user. Additionally, achieving 95% accuracy for wheelchair users, 90% for crutch users, and sub-25-cm distance-estimation precision, representing a 50-57% improvement over baseline methods. CLAHE preprocessing restored nighttime detection performance by 2-3%, enabling reliable operation in various lighting conditions. SUMO simulations showed that even maximum pedestrian extensions generated only modest, controlled slowdowns, while no-pedestrian scenarios matched free-flow baselines, confirming minimal traffic impact. Behavioral insights derived from real-time pedestrian detection and driver monitoring were translated through a smartphone app-based bi-directional feedback system. Pedestrians received vibration, audio, and visual cues such as extended-time notifications, while drivers received alerts about ongoing crossings. By centralizing various external conditions, stimuli, and information at crosswalks, SmartBlink comprehensively understands the and then minimizes the risks posed to pedestrians at intersections and crosswalks. Overall, SmartBlink demonstrates how behavior-based urban infrastructure can transform intersections from static vehicle-centered systems into adaptive systems that respond to real human mobility patterns and driver decision-making, fostering intersection environments where individuals of all mobility levels can move with greater autonomy, safety, and confidence.

**When Seeing Overrides Feeling: How Virtual Reality Influences Object Recognition and Perception**

Vivienne Liedtke

Perception is based on how the brain identifies senses, two of them being sight and touch. These senses are transmitted from sensors to different brain regions separately, each carrying their own information that will be combined with the other to form the perception of what is happening (Eye Health Center, 2025). However, perception is not always accurate, meaning the brain may choose to follow one sense over the other (Kathleen Yale, 2014). Understanding how and why this happens can benefit recovery in the medical field as it pertains to many disorders, whether it be genetic or due to injury (Kurtzgesagt – In a Nutshell, 2025). Manipulating these perceptual processes can be used for therapy and rehabilitation regarding difficulties and patterns such as trauma and phantom limb experiences. In the experiment, participants were asked to place their hand inside a box and guess the object placed inside after ten seconds. Twelve participants had their eyes closed while the other thirteen focused on an image projected on the screen that did not always match the touched object. It was hypothesized that the percentage of correct responses would increase with age. Regardless of sex, the age group 45+ guessed the object correctly 76% of the time compared to 88% in the 13-18 age group. The experiments data supports the resulting theory that regardless of sex, humans (likely increasing with age) rely on sight more so than touch to form the perception of the surrounding world. Future studies, including a more immersive virtual reality set-up with a wider variety of sensory options, can further aid in discovering which aspects of perception are more dominant.

Bancroft School

**The Impact of Different Modes of News Media Consumption on Extremist Political Beliefs**

Helen Taylor

In the United States today, political polarization is the worst it has been in five decades (Desilver, 2022). Polarization such as this is a major contributor to political violence due to its "demonization of other groups," (Political Polarization in the United States, 2024). Therefore, understanding the root causes of political polarization is an urgent matter to avoid further division and violence. One of the most immediate determinants regarding the formation and potential extremism of someone's political opinions is how they consume news media. In 2025, 56% of U.S. adults reported having often gotten their news from digital devices; of this 56%, 31% most often consumed news from social media or podcasts (News Platform Fact Sheet, 2025).

This study consists of two surveys. The responses from the first survey measure the correlation between the type of news media consumed and the presence of strong, or extreme, beliefs. In the second survey, participants' answers are used to determine how different types of news media directly impact the extremism of their beliefs.

The results of this study contradict the hypothesis. In the first study, it was found that television was the only platform with a positive correlation between the time spent watching television news and the percentage of extreme beliefs; the other platforms had no correlation. In the second study, it was found that newspapers increased participants' percentages of extreme answers the most, at a roughly 32% increase, followed by podcasts and television. Social media was found to increase the percentages of extreme answers the least, with a roughly 8% increase.

**The Association between BMI, Demographic Factors, and Progression to Multiple Myeloma**

James Tao, Christine Tao

A preliminary PubMed review found limited research on how socioeconomic and educational levels affect BMI and potentially increase progression to multiple myeloma. This study asked “Does higher BMI increase the likelihood of progression from MGUS/ SMM to multiple myeloma, and are lower income and educational levels associated with increased BMI in this population?” It was hypothesized that if study participants have higher BMI, then they will be more likely to progress from MGUS/ SMM to MM, and if study participants have lower income and lower education, then they will be more likely to have higher BMI.

Categorical variables gathered from the PCROWD baseline questionnaire (such as, BMI group, sex, education, income) were summarized using frequencies and percentages, while continuous variables (BMI and age) were summarized using medians and interquartile ranges (IQR). BMI was calculated from self-reported height and weight using the formula: weight (kg)height (m)2, and was categorized into 4 groups: underweight (<18.5kg/m2), normal (18.5-25.0kg/m2), overweight (25.0-30.0kg/m2), and obese (>=30.0kg/m2). Then, chi-square tests were performed to evaluate associations between socioeconomic factors and BMI category for (1) BMI by education and (2) BMI by income. Time to progression from MGUS/ SMM to MM was analysed using Kaplan-Meier survival curves, stratified by the categorical variables. Finally, log-rank tests were used to determine whether progression-free survival differed significantly between groups.

BMI category was significantly associated with progression to MM (p-value=0.0058), as well as with income (p-value=0.0093) and education (p-value<0.0001). Males also progressed faster than females (p-value=0.0006). These findings support the hypothesis that socioeconomic disadvantage is linked to increased BMI in individuals with SMM/ MGUS and that higher BMI is associated with increased progression to MM; however, socioeconomic status was not directly associated with progression to MM.

From a public health perspective, this suggests that social factors may contribute to obesity-related disparities in disease risk and progression. Addressing socioeconomic barriers to healthy weight–such as access to nutrition and health education–may be important for reducing disparities and improving long-term outcomes in this population.

Massachusetts Academy of  Math & Science at WPI

**Researching the Effects of Indian Carnatic Music on the Behavior of Drosophila melanogaster in an Autism Spectrum Disorder Model**

Ananth Gomatam

Autism spectrum disorder (ASD) is a neurological condition that affects communication, social behavior, and learning. Due to its complexity and wide range of symptoms, there is currently no cure, and interventions focus on symptom management and behavioral support, including Music Therapy (MT). MT uses structured musical experiences, such as listening to or playing music, to support behavioral and cognitive outcomes in individuals with ASD. Current MT practices primarily rely on Western music, including classical and popular genres (Qiu, 2024), with limited exploration of non-Western musical traditions. Indian Carnatic music, a classical South Indian genre, is based on melodic frameworks called ragas, many of which are historically associated with specific emotional and therapeutic effects. However, Carnatic music has not been formally studied within the context of MT. This study investigates the effects of two Carnatic ragas, Bilahari, traditionally linked to happiness and communication, and Mohanam, associated with focus and decision-making, while also comparing them to classical and pop music (Qiu, 2024). Their effects were examined in Drosophila melanogaster using wild-type flies, dfmr1 mutant ASD model flies, and control groups. Social interaction was evaluated using a social space assay, and cognitive function was assessed through a negative geotaxis assay. Results showed that both Raga Bilahari and Raga Mohanam significantly improved cognitive function in ASD model flies compared to pre-music and classical and pop groups ($p < 0.0001$). Additionally, Raga Bilahari significantly improved social interaction compared to pre-music ($p < 0.001$) and pop music ($p < 0.05$), supporting further investigation in human studies.

Worcester Academy

**Beyond Food and Fitness: Highlighting the Role of Adverse Childhood Experiences in Youth Obesity**

Anwita Wadekar

Youth obesity is traditionally addressed by counseling about lifestyle, or diet and exercise habits. Growing clinical evidence points to the influence of adverse childhood experiences (ACEs) on youth obesity, but we do not understand whether ACEs contribute meaningfully beyond lifestyle factors. This research develops a comprehensive framework to identify youth at risk for obesity and to compare how much ACEs contribute relative to diet and exercise. The framework is based on a secondary analysis of a nationally representative dataset; the 2023 CDC Youth Risk Behavior Survey (YRBS) (students grades 9-12, n = 7902) using multiple machine learning models. Neural networks showed strong discrimination and are able to identify at-risk youth (Sensitivity ~ 0.87, AUC ~ 0.85) compared to the lifestyle model that considered only diet and exercise (Sensitivity ~ 0.33, AUC ~ 0.31). Mediation analysis, prominently used in psychological research, revealed that the influence of ACEs on obesity risk is transmitted indirectly via substance use and mental health pathways, but not through the lifestyle pathway. These pathways mediate the relationship between ACEs and obesity risk only partially, retaining the direct effect. These results suggest that obesity risk may not be fully attributed to diet and exercise behaviors, and call for expanding pediatric screening to biopsychosocial factors. To translate this approach into clinical workflows, a prototype clinical decision support (CDS) tool was built to collect childhood experiences and health behaviors non-intrusively. CDS can allow clinicians to holistically assess upstream contributors and plan individualized care. It may also suggest school-based or community-level interventions.

**The Gravity of the Group**

Rafeef Alrasheed

Pioneer Charter School of Science II (PCSS-II)

**Assessing the Behavioral and Reproductive Effects of Teabag-Derived Micro- and Nanoplastics in Caenorhabditis elegans**

Adil Tigli

Microplastics are found in everyday exposures that most people tend to overlook, such as tea bags. This experiment explores the neural and reproductive side effects of teabag-derived micro- and nanoplastic solutions in Caenorhabditis elegans. Caenorhabditis elegans is frequently used in translational research topics similar to mine due to its conserved biological pathways with humans, namely in their neural and reproductive pathways. By exposing cultures of C. elegans to respective micro- and nanoplastic–containing tea bag leachate or control sterile water solution, toxicity in reproduction and locomotion in these roundworms was assessed. Locomotion measurements through thrashing behavior at 24, 48, and 72-hour intervals, and reproductive assessment through progeny count after 72 hours, were utilized to measure the biological consequence of the ingestion of tea brewed from teabags. The experimental culture of C. elegans showed significant decreases in locomotion over time and a decrease in total progeny count, which was measured by p-tests and Cohen's d effect size evaluations.

Algonquin Regional High

**Detection of Alzhemier's Disease and Related Dementia(ADRD) and Cognitive Impairment: Impacts and Supports for Patient and Society**

Michelle Liu

Alzheimer’s Disease and Related Dementias (ADRD) affect millions worldwide, with up to 152 million projected cases by 2050. In the U.S., approximately 200,000 adults aged 30–64 have ADRD, and total care costs are estimated at $360 billion in 2024. Early diagnosis is critical for timely care planning, treatment initiation, and caregiver support, yet many individuals experience substantial delays between symptom onset and formal diagnosis. This study aims to identify barriers and facilitators of early ADRD detection, examine associated risk factors, and explore ways to support patients and prospective patients in recognizing cognitive decline.

We will use a mixed-methods approach integrating primary and secondary data. Interviews and surveys with primary care providers (PCPs) will capture experiences and practices in identifying cognitive impairment, while surveys with older adults will assess awareness and self-monitoring behaviors. Publicly available datasets, including the NORC Dementia DataHub, CDC BRFSS Cognitive Decline Module, and County Health Rankings, will provide information on structural, social, and behavioral determinants of diagnosis patterns. Quantitative data will be harmonized and analyzed using multivariable regression, while qualitative data will be analyzed thematically.

Expected outcomes include identification of key barriers (e.g., rurality, low education, limited PCP access), evaluation of detection rates by providers and patients, and recommendations for policy and practice. Findings will guide public health campaigns, health systems, and advocacy groups to improve early ADRD detection, patient awareness, and support healthy aging.

O'Bryant School Math/Science

**An Examination of Age-Dependent Cognitive Attributions of Luck and Skill in Success Outcomes**

Binty Faruk, Alexander Braga, Samantha Lee

How do different groups of people perceive the causes of success, and what demographic factors shape those perceptions? This project investigates whether people attribute success to hard work and skill or to luck and circumstance, and how those beliefs change across age groups and socioeconomic backgrounds. Prior research suggests that personal experience, environment, and economic status influence perceptions; however, there's a lack of research that examines how these factors interact across generations in the same community. We hypothesized that older age groups would be more likely to attribute success to skill and effort, while younger groups would place greater emphasis on luck, and that individuals from higher-income households would be more likely to favor skill contributing to success. For our data, we created and analyzed our Qualtrics survey with 229 participants across four age groups: 12-18, 19-25, 26-45, and 46+. To measure this research, we created eight belief statements about success on a 1-5 scale, as well as a ranking of five factors, including hard work, luck, connections, talent, and parental success. The results showed that higher-income teens scored higher on hard work belief (3.88 for over $100k+ households vs. 3.04 for under $30k), while all four age groups ranked hard work last when they prioritized all the factors. The ranking went down with age from 2.81 among teens to 1.58 among the 46+ group. Additionally, we interviewed 24 applicants who agreed to be interviewed. These interviews built on the fact that teens emphasized education and breaking milestones, working adults (26-45) stressed the role of connections and inequality, and older adults (46+) defined success as personally subjective while acknowledging that parental background influences outcomes by as much as 90%. Ultimately, these findings reveal a gap between the beliefs and priorities across demographics, suggesting that even though people believe in hard work, they recognize that luck, connections, and circumstances play a larger role in determining success.

Boston Latin School

**Multitasking Mania: Identifying Factors That Influence Successful Performance**

Soleil Desai

Multitasking is an important skill in both academic and professional environments. This project investigated whether innate and environmental factors influence an individual's ability to successfully multitask. I hypothesized that factors such as gender, athletic participation, and environmental conditions would significantly affect multitasking performance. To test this, 31 students in 7th and 9th grade participated in a dichotic listening experiment. Participants first listened to a passage and answered comprehension questions. They then completed a second trial in which a different passage was presented with background noise from a school cafeteria, followed by similar questions. Performance was quantified as the percentage of correctly answered comprehension questions. Statistical and subgroup analyses were conducted to evaluate differences between the control and multitasking conditions, as well as between the tested factors. The results showed no significant relationship between the tested factors and multitasking ability. However, a statistically significant difference was observed between performance in the control and multitasking conditions, with 16 participants showing improved scores on the second trial, suggesting a possible practice effect. These findings indicate that multitasking ability may be more influenced by learned skills or familiarity with the task rather than the specific factors examined in this study. Future research with a larger sample size and additional variables could provide further insight into individual differences in multitasking performance.

Billerica Memorial High School

**Exploring Sleep Recovery Through Negative Geotaxis in Drosophila**

Devina Paul

Sleep is necessary for maintaining cognitive functions throughout the day, such as memory consolidation, decision-making, and learning. Adults are recommended to sleep at least seven hours a night, but it often becomes compromised for those who work in fast-paced environments and for those with frequent exposure to artificial lighting. Sleep is regulated in a two-process model, which involves circadian rhythms and homeostatic maintenance. Such processes are also found in the model organism D. melanogaster. In this continuation study, wild-type and short sleep (SIP_S1_1) flies were stored in various lighting conditions. A control group was placed under 12:12 L/D cycles for the entirety of the study (12 hours of light, 12 hours of darkness), where flies exhibit established behavioral patterns of activity. For the first 48 hours, two experimental groups were exposed to 12:12 L/D cycles. For the next 48 hours, the experimental groups were exposed to constant lighting for sleep deprivation to occur. At the end of the study, the groups were placed in more favorable conditions in order to let recovery sleep happen: one group was placed back in the 12:12 L/D cycle, while the other was placed in a 6:18 L/D cycle. Negative geotaxis, the ability for Drosophila to climb up the wall of an enclosed space when startled, was observed through assays conducted between lighting conditions. The data suggested that negative geotaxis did not decrease in wild-type flies after exposure to constant lighting, but did decrease in SIP_S1_1 flies.

Keywords: sleep, sleep deprivation, rebound sleep, Drosophila, lighting cues, geotaxis

The Winsor School

**Exploration of Microplastic Uptake in Vegetables for Public Health**

Irene Tian

Micro- and nanoplastics (MNPLs) are polymeric materials that are pervasive environmental contaminantsdefined by particle sizes smaller than 5mm in diameter. Currently, a noticeable lack of research in MNPL behavior and impact has limited the understanding of the potential long-term impact of MNPLs in our environment, especially in food security and public health. Additionally, existing research in this field is often inconclusive, contradictory, and expensive due to a lack of technical standardization and cumulative research. This study explores MNPL exposure to common vegetables using Allium fistulosum as a case study. Through the observation of intentionally contaminated and store-bought samples, the collected data suggests definitive MNPL uptake in Allium fistulosum and the negative physiological effects of said uptake. A novel, effective, and inexpensive digestive solution of 3% H☐O☐ for MNPL extraction was tested and suggested promise as a comparable digestive solution. Surface Enhanced Raman Spectroscopy (SERS) was tested for MNPL analysis and similarly showed great promise. Ultimately, the findings of this paper concluded that within soil environments, “spiked” Allium fistulosum had an average of 140.303 particles/mL. Similarly, for Allium fistulosum solely grown in water, “spiked” samples had an average of 192.604 particles/mL. MNPL accumulation within store-bought Allium fistulosum was found at a substantially greater level at 1,784.277 particles/mL. These findings suggest that commonly consumed vegetables may represent a critical pathway for MNPL ingestion.

**The Effect of Different Materials For Water Contamination Filtration**

Elmeria Cheung, Michelle Chen, Anna Li

The type of modified bioplastic (maltodextrin, sodium alginate, and agar agar) was created to test the effectiveness of filtering out phosphate-contaminated water over a 12-hour period in order to determine if the modified bioplastic is effective in minimizing the detrimental effects of eutrophication. The hypothesis for this experiment is as follows: if synthetic wastewater contaminated with phosphate were passed through different bioplastic filters based on different polysaccharides (agar agar, maltodextrin, and sodium alginate), then the synthetic wastewater flowed through the sodium alginate bioplastic would have the lowest average level of concentration of phosphate after 12 hours. This experiment was conducted by creating a modified bioplastic and designing a filter using materials such as a 1-liter soda bottle, gravel, rocks, cheesecloth, and the modified bioplastic placed on top of the cheesecloth. After the synthetic phosphate solution was created, the solution was poured through the filter and left for 12 hours; after, the phosphate level was tested. Results showed the sodium alginate modified bioplastic was the most effective at filtering out phosphate, as the filtered water had the lowest average phosphate level. These results can be attributed to sodium alginate's polarity and its ability to form dipole-dipole and hydrogen bonding. Future applications of this project can be applied in developing effective strategies at combating nutrient pollution in marine ecosystems and reducing the possibility of eutrophication.

**Exposing the Effects of Noise Pollution Through Eisenia hortensis**

Andy Liu, Alec Piepergerdes

In previous studies, including one conducted by Vellila et al., vibrations generated from noise pollution were found to disrupt the natural behavior of animals, namely earthworms, who react to noise in their environment and use it to avoid predation. In order to better understand the negative health implications of noise pollution, researchers attempted to recreate the conditions many animals face. In this experiment, Eisenia hortensis, more commonly known as European Nightcrawlers, were introduced to an enclosure and observed in order to learn their normal behaviors. Then, after their normal behaviors were determined, the earthworms were then exposed to levels of noise pollution mimicking that of a construction zone or large venue, and their behaviors during this period were monitored in order to measure how they varied from their normal behaviors. The researchers found a strong correlation between the noise and negative behaviors in the earthworms, highlighting the importance of addressing this issue and drawing attention to the severe health implications noise pollution has.

**Modeling the Invasive Spread of Oriental Bittersweet and Quantifying Bias in Citizen Science Data**

Lorcan Purcell, Jing Yao Yang

Oriental Bittersweet (Celastrus orbiculatus) is one of the most harmful invasive species in the northeastern United States, destabilizing forests by climbing and choking native trees. However, the factors driving its habitat suitability and the reliability of citizen science occurrence data remain poorly understood. We used species distribution models (SDMs) to study how climate and anthropogenic disturbance affect Bittersweet occurrence, whether disturbance variables improve prediction beyond climate alone, and whether observer bias in citizen science data distorts estimated habitat associations. Binomial logistic regression models were fitted using Forest Inventory and Analysis (FIA) presence-absence records from 5,190 plots (2003–2024) and 32,992 GBIF citizen science occurrences, with climate, canopy cover, housing density, and Wildland-Urban Interface (WUI) class as predictors. Adding disturbance variables to a climate-only FIA model improved AIC by 302 and increased AUC from 0.877 to 0.921 (10-fold CV, $p < 0.001$), indicating that human disturbance significantly refines predicted establishment within climatically suitable areas. However, climate remains the dominant factor: we document a 198.8 km northward shift in mean occupied latitude between 2003 and 2024 (+0.0542 °C/year, $p = 0.0067$) and project a further 58.1 km northward shift by 2050. Comparison of FIA and GBIF disturbance coefficients revealed systematic divergence: the WUI Uninhabited coefficient was strongly negative in the FIA model (−1.19) but positive in unthinned GBIF data (+0.53), a sign reversal that persisted after spatial thinning (+0.12). This residual divergence likely reflects fundamental differences in sampling universe rather than pure accessibility bias, suggesting that citizen science data may systematically misrepresent habitat associations in areas with low human activity.

Keywords: Invasive Species; Species Distribution Modeling; Citizen Science; Climate Change; Ecology

**From Hair to Habitat: Breaking Down Cosmetic Pollution**

Emily Carter

Polyethylene glycol (PEG) is a synthetic polymer commonly found in cosmetic products such as shampoos and conditioners. Its widespread use raises environmental concerns due to its accumulation in natural ecosystems. The purpose of this experiment was to determine whether Pseudomonas putida can aid in the degradation of PEG. A liquid culture of the bacteria was prepared and exposed to three different concentrations of PEG across 90 conical tubes, which were set at room temperature for one month. After that period, pH levels were measured to assess changes associated with polymer breakdown. The results indicate that P. putida is capable of degrading PEG, as shown by variations in pH among the samples. These findings suggest that this bacteria could have practical applications in water filtration systems, particularly in reducing polymer pollutants and microplastics.

**Small Particles, Big Impact: Assessing Microplastic Pollution in Massachusetts Water**

Ayan Nafee, Areeb Muhammad Noor

Microplastic contaminants in drinking water pose serious risks to human health. In this project, we designed an experimental setup to quantify microplastic contamination and investigate whether significant variations exist across different towns in Massachusetts. Tap water samples were collected from three towns and analyzed using a membrane filtration system with a vacuum funnel. To enhance detection, we applied Nile Red dye to the filters, allowing microplastics to be visualized under fluorescent light using a digital microscope. Multiple images were captured for each sample. Direct visual estimation with the naked eye was not possible from images. To address this, we utilized an image-processing tool to analyze the images and assign density rankings on a scale from 1 to 10, where 1 represents the lowest and 10 the highest microplastic density. An AI-based tool was then trained to estimate ratings for all samples. The experimental results revealed significant variation in microplastic levels across the towns, with the lowest levels observed in Canton and higher levels detected in Mansfield and Sharon, respectively. Use of ANOVA statistical analysis confirmed that these differences are statistically significant. Further review of municipal water treatment reports indicated that Canton employs more effective strategies such as greater reliance on groundwater sources, better maintenance of treatment facilities, and more comprehensive treatment processes which likely contribute to its lower microplastic levels.

**Banana Plastic: Evaluating the Strength, Flexibility, and Real-World Potential of Banana-Peel Bioplastic**

Jad Khatib, Yahia Sorour, Mohamad Sheikh Qasem

Plastic pollution is rapidly becoming one of the biggest pollution problems because petroleum-based plastics take years to decompose. This project explored the possibility of using banana peels to create biodegradable plastic. Banana-peel bioplastic was created and experimentation was done to see how altering the amount of corn syrup plasticizer would change its mechanical properties.

Three trials were done with low, medium, and high concentrations of corn syrup with every other ingredient remaining constant. Banana peels were blended into a paste, mixed with vinegar, water, and corn syrup, then boiled until a plastic-like substance formed that could be dried into a film. Once dry, the three samples were flexed back and forth to test for flexibility and weighted until they broke to test for strength.

The data concluded that as the amount of corn syrup went up, so did flexibility. Strength went up from the low to medium concentration and decreased from medium to high concentration. The overall strongest and most flexible sample was the medium corn syrup sample.

For further application of this project, the material was molded into primitive cups, and the possibility of using it to preserve food was considered.

**The Effects of Different Percentages of Vermicompost on Different Vegetable Types.**

Sophia Reitsma

Vermicompost is an addition to soil made from earthworm excrement, which provides the nutrients necessary for the soil–improving its health. Too much vermicompost can negatively affect plant growth due to the higher concentration of soluble salt. To test this, three different plant types were chosen; Green onions, Lima beans, and Cherry Belle Radishes. There was a control of 0% vermicompost and an experimental of 20% vermicompost, where 30 seeds were planted from each plant type in both the experimental and control. The student predicted that the vegetables planted in the 20% of earthworm excrement mixed with soil will have the highest biomass.

Shrewsbury Sr High

## Sustainable Sips: Engineering and Experimental Evaluation of Biodegradable Straw Formulations

Annie Li

Plastic straws are widely used but contribute significantly to environmental pollution as they are not biodegradable. Approximately 500 million plastic straws are used daily in the united states alone, that equates to roughly 12 million pounds of plastic waste daily. Annually around 33 billion pounds of plastic enter the ocean. Though there are both reusable and disposable straw alternatives, none are perfectly optimal. This project investigates whether biodegradable materials, including starch, cellulose, and plasticizers, can be formulated into a material that can serve as a sustainable alternative while maintaining functionality. Biodegradable straw material was developed after various trials and tested for durability, hydrophobicity, and stability in different pH levels. In the experiments, plastic straws were used as the control group and the formulation was compared against both plastic and paper straws. The results showed that while the biodegradable straw formulation was more hydrophilic and slightly less durable than plastic straws, they remained functional for short-term use and performed consistently across different pH environments. For hydrophobicity there was a p-value of $p \approx 2.6 \times 10$□$^{12}$ between plastic and the formulation indicating there is a statistically significant difference. This is an area that would be improved on in the future. The biodegradable straw formulation was found to be more hydrophobic than paper straws and although less durable, this could be due to various factors not taken into account. The p-value between the formulation and paper straws was p ≈ 4.1 × 10^-6 indicating a significant difference between the two materials. This shows that the starch-cellulose formulation was significantly more hydrophobic than the paper material. These findings suggest that the starch-cellulose-based straw material is a promising eco-friendly alternative to plastic straws, with potential for further optimization in strength and water resistance.

**Dose-Dependent Transfer of PFAS from Irrigation Water to Edible Tissues of Radish and Lettuce and Evaluation of Activated Carbon Filtration as a Mitigation Strategy**

Sahana Chaubal

PFAS (Per-and-polyfluoroalkyl-substances) are synthetic compounds invented to resist heat, water, and stains. They are found in numerous everyday products, and since they do not naturally break down, they build up (Forever Chemicals). Exposure to PFAS is linked to cancer as well as immune system and hormone disruption. Plant uptake of PFAS from contaminated irrigation water is poorly understood.

This study examined whether irrigating with environmentally relevant PFAS concentrations leads to measurable, significant, and dose-dependent, yet invisible, accumulation of PFAS in plant tissues. It also examined whether activated carbon filtration reduces transfer. I hypothesized that

1. PFAS accumulation would increase dose-dependently,
2. Growth and visual traits would not reliably predict contamination, and
3. Activated carbon would reduce uptake.

Edible radish (Raphanus sativus) and lettuce (Lactuca sativa) were irrigated with either PFAS-free control or increasing PFAS concentrations (including filtered treatment). Plant growth parameters and a blind visual scoring were measured, after which LC–MS was used to quantify PFAS in the plant tissue.

Growth and visual traits showed no dose-dependent decline, and blind visual scorings (n=67) were at chance levels. However, plant tissue concentrations were dose-dependent and significant (2-39x EU EFSA limits). Activated carbon filtration significantly reduced (84-91%) PFAS concentrations without impacting growth. These results demonstrate that PFAS in plants is chemically accumulating but visually invisible, underscoring the need for chemical testing when evaluating contamination risk.

**Which Filtration Method Can Most Efficiently Remove Microplastics?**

Angelica Martinez

Microplastics are small plastic particles that have become increasingly notable within air quality and water sources. They are a growing concern because of their possible impacts on human health and the environment. Microplastics can be absorbed, distributed, metabolized, and excreted by the human body, potentially leading to inflammation, DNA damage, and an increased risk of cancer development. The purpose of our experiment was to determine which filtration method most effectively removed microplastics from different water sources using accessible materials. Three filtration methods were used including a homemade sand filter, a membrane filtration system, and distillation. Each water source was tested before and after filtration to determine how effective each method was by analyzing and comparing the difference in absorption. We found that the membrane filtration system removed the greatest amount of microplastics. This study demonstrates that filters such as a membrane straws can be an affordable and effective way to improve drinking water quality, especially for those who lack access to expensive filters and need fast, reliable, clean drinking water. This however, disproves our hypothesis that distillation would be the best filtration method due to a difference in boiling points that would evaporate the water, condense, and leave behind pollutants.

**How Does Temperature Affect Medicinal Production in Fungi?**

Jailyn Serrano

This experiment investigated how temperature affects the growth of medicinally important fungi, specifically Aspergillus niger and Penicillium chrysogenum. Because many medicines are produced using fungi, understanding how rising global temperatures may affect fungal growth is important for future medicinal production. Fungal cultures were grown at three temperatures (20 °C, 25 °C, and 30 °C), and growth was evaluated using a standardized visual growth rating scale based on colony density and spread. Three trials were conducted to ensure consistency.

Results showed that fungal growth increased as temperature increased for both species; however, the most balanced and consistent growth occurred at 25 °C. At 20 °C, growth was slow and limited, while at 30 °C, growth was rapid but crowded. Aspergillus niger demonstrated stronger growth at higher temperatures compared to Penicillium chrysogenum, supporting the hypothesis that Aspergillus niger is more tolerant of heat.

These findings suggest that temperature plays a significant role in fungal growth and may influence which fungi are most suitable for medicinal production as global temperatures rise. Understanding fungal temperature tolerance may help scientists adapt or maintain medicine production in a warming climate.

Littleton High School

**Evaluating Environmental Pollutants Using a Biodegradable Algae-Based Enzyme Biosensor**

Lasya Muthyala, Caitlin  Stimpson

This study investigates the use of a biodegradable algae-based enzyme biosensor to detect environmental pollutants, addressing the growing need for eco-friendly, low-cost monitoring methods. As industrial and agricultural activities increase chemical runoff, detecting pollutants like nitrates, phosphates, and hydrogen peroxide is crucial for maintaining water quality. This research combines biology, chemistry, and environmental science to evaluate whether algae, embedded with catalase enzyme and a colorimetric dye, can act as an effective biosensor. Biosensor samples were exposed to varying concentrations of pollutants, and their colorimetric responses were measured using a spectrophotometer. Results showed that both potassium phosphate and hydrogen peroxide induced concentration-dependent increases in absorbance, with hydrogen peroxide eliciting the strongest reaction. Statistical analysis, including ANOVA, confirmed significant differences between treatments and the control. These findings demonstrate that algae-based biosensors can serve as sustainable, biodegradable platforms for pollutant detection, offering a practical alternative to conventional synthetic sensors. Future research should investigate additional pollutants, optimize biosensor composition, and explore field applications for environmental monitoring.

**Swimming in Silver: The Effects of Nano-silver on Daphnia Heart Rate**

Gustavo Borges, Jad Chaibi

Nanosilver is increasingly used in everyday consumer products worldwide, raising concerns about its potential impact on aquatic ecosystems. We are interested in this project, as understanding nanosilver effects on aquatic organisms like Daphnia, can assist identifying environmental risks, and promoting safer product development.

**Analysis of Water Level Behavior and Residual Surge During Extreme Flooding Events**

Jason Lu

Flooding is one of the most damaging natural hazards in the United States costing billions of dollars every year. Astronomical water level prediction can significantly underestimate water levels during extreme events, while unique terrains and distinct weather patterns determine the flooding characteristics of each inland community. This research develops an interactive framework to help communities better understand flood risk and prepare for extreme events by combining historical data visualization, analytical tools, and key metrics to show how flood conditions change over time and across locations. Coastal flooding is analyzed through residual surge to separate storm-related water level events from regular tidal behavior. Analysis reveals that hurricane-induced residual surges of similar intensity have increased over time, indicating elevated baseline flood risk. Early-stage residual surge is investigated to see whether regression analysis can predict peak surge height during storms. Inland analysis demonstrates that upstream water levels can serve as early warning indicators for downstream flooding, an analysis showed a prediction precision of 78% for flooding in Hunt, TX and a 490-fold increase in flooding likelihood. These findings highlight the importance of integrating coastal and inland data to improve flood monitoring and early warning systems to prevent tragedies like the 2025 Camp Mystic flood in Texas. A pilot Streamlit dashboard tool is developed to allow local communities to have easier access to complicated water data and better understanding of flooding risks to support more effective preparedness and risk mitigation.

Keywords: storm surge, residual surge, flood prediction, coastal flooding, inland flooding, NOAA tide data, USGS stream data, flooding early warning systems, data visualization

**Investigation of the Multiyear Effects of Road Salting Practices on Muddy River Salinity Levels Over Time**

Isabella Winey

Road salt use is on the rise all across the country, with only limited research currently investigating its effects on local ecosystems. Particularly in areas with high road density, such as cities, it is essential to gather more data on the salinity of urban waterways throughout the winter. Within these metropolitan ecosystems, increased salinity is known to negatively impact amphibian reproduction and microorganisms, as well as damage trees lining waterways. In addition, high salinity runoff can seep into groundwater, a primary source of drinking water, not to mention the corrosion it causes to crucial infrastructure. This project collected water samples from the Muddy River in Boston between February and April, and spanned over 4 distinct salting events which corresponded to anticipated snowfall. It was predicted that samples taken closer to roads with steeper topography and/or lower tree density would increase the chloride ion levels more quickly than locations with the opposite characteristics. Across all locations, it was found that the salinity of the Muddy River doubled after salting events, when compared to minimum measurements for each site. During later rounds of testing, significant reductions of salinity occurred, particularly between 24 and 72 hours after the salting event took place. In addition, a positive relationship was observed between the number of adjacent roadways and the magnitude of salinity change. Therefore, this project found that road salting practices significantly increased the salinity of the Muddy River, particularly in areas with greater road density, endangering the urban ecosystem and the city’s infrastructure in a preventable way. Future policy changes could include shifting to alternative deicing agents and increasing education surrounding environmentally friendly salt use.

**Global Analysis of the Effects of Fire Activity on Solar-induced Chlorophyll Fluorescence (SIF) Using Machine Learning**

Qinghe Zhao

Understanding how fire activity affects post-fire vegetation recovery is essential for sustainable forest management, as fires can both disrupt forest ecological balance and promote species diversity and natural regeneration. This study focused on the development of a random forest machine learning model to investigate the relationship between fire activity, in particular fire intensity, and changes in photosynthetic activity as indicated by the Solar-Induced chlorophyll Fluorescence (SIF). Analyzed on a global scale, our results revealed a nonlinear relationship between fire intensity and SIF, with moderate-intensity fires possibly stimulating a weaker chlorophyll biosynthesis response in vegetation compared with other Fire intensity levels. Feature permutation importance analysis suggests that fire location provides stronger predictors of SIF than fire characteristics.

**Iron Oxide (Red vs. Yellow vs. Brown) Pigments in Acrylic Paint against Environmental Stressors**

Cindy Yuan

Art is an essential way that humans leave behind pieces of themselves and their culture in hopes that their thousands of hours of work will be seen and understood by people in the future. Ancient creations like cave art in the Temples of Dunhuang in China, which used abundances of inorganic iron oxide pigments, are fading away and being damaged due to natural environmental stressors such as salinity, humidity, and UV exposure. This study investigates iron oxide paints of red, yellow, and brown colors against UV light and salt water sprays over the span of 21 days. Results under control conditions unexpectedly developed more change than those under environmental stress simulation, aside from one outlier of red paint in salt water having greater change than its control, disproving the basis of the original claim likely because the length of the experiment was too short. If not for this outcome, the analysis would have continued by comparing the colors' average slope magnitudes of RGB (brightnesses of red, green, and blue within a color) components within each environmental stressor. Yellow paint had the least amount of fading under both UV and salt water degradation, which is not aligned with the hypothesis. Although, this cannot be taken as the ultimate answer, as the overall degradation under environmental stressors was actually less than that of the control. Future iterations of this experiment that are representative of true deterioration effects on these paints can allow for more prioritization on preserving the most unstable and fade-prone pigments of both ancient artworks and those to-be-made in the future.

**Exploring the Real-World Feasibility of PET-Plastic Degradation by TfCut2 Enzymes for Plastic Bioremediation**

Martin Wong, Benson Wong

Prior research relating to plastic degradation has been conducted in highly regulated settings, where shaking plate incubators, pure polyethylene terephthalate (PET) plastic sheets, and high molarity buffers were used. Conclusions have been made about TfCut2 enzymes' effective degradation activity at high temperatures. This paper seeks to explore whether such conclusions still apply when such enzymes are applied in less heavily regulated environments, where they're exposed to common stressors like greater pH fluctuations and static environments. A non-pathogenic strain of E. Coli BL21 (DE3) bacteria was used as a host for recombinant protein secretion and purification, and its suitability along with cutinase enzymes for agricultural applications is explored through monitoring plastic mass changes and visual changes. A parallel experiment was also conducted with cell-free purified proteins to compare relative efficacy between in-vivo and in-vitro systems. Based on image analyses of visual changes for the plastic pieces and calculations of a Relative Degradation Score (RDS) derived from changes in the plastic edge lengths, results indicate that while only minimal weight changes were found, surface level degradation was nevertheless registered. Such changes were amplified for the 70°C tests, where degradation percentages from day to day were highest compared to tests at 37°C. However, on average, the cell free-synthesized proteins performed better both at 70°C (a maximum of -48.17% border length changes compared to -40.77%) and at different concentrations for the 37°C tests, suggesting potential differences in protein expression and purification between in-vivo and in-vitro methods.

Key terms: Recombinant protein, E. Coli, Relative Degradation Score (RDS)

**From Clear to Cloudy: Uncovering the Complex Factors Shaping Pond Water Quality**

Grace Gu

This project investigates how environmental factors like pH, turbidity, and dissolved oxygen levels influence the changing quality of a local pond. This will ultimately reveal why pH levels vary in the tap water of Winchester High School, which is tested through these collections of water samples at different ponds.

**Uncertainty□Aware Storm□Time Thermospheric Density Forecasting for Satellite Collision Risk Reduction**

Kirpal Singh Rayat

In May 2024, the most severe geomagnetic storm in two decades forced nearly half of all active low Earth orbit satellites to maneuver simultaneously, disrupting global conjunction assessment pipelines and causing twelve Starlink satellites to be lost to uncontrolled orbital decay. These failures stemmed from a fundamental gap: current density forecast models provide no measure of their own uncertainty, leaving satellite operators unable to distinguish dangerous conjunctions from false alarms when orbit predictions matter most.

This study developed a three-layer forecasting pipeline to address this gap. An LSTM neural network with 338K parameters was trained on 6,813 satellite density samples spanning five spacecraft and twenty years of solar activity to forecast 72-hour thermospheric density trajectories from space weather indices and initial observed density. Split conformal prediction was then applied to generate distribution-free 90% prediction intervals requiring no assumptions about error distribution. Finally, Monte Carlo orbit propagation with 300 trajectories translated density forecast uncertainty into three-dimensional position uncertainty ellipsoids for two representative satellite classes at 400 km and 500 km altitude.

Evaluated on held-out Halloween 2003 superstorm data (Dst = −383 nT), the LSTM reduced storm-time density RMSE by 25–41% across 24–72 hour horizons compared to the persistence baseline. Conformal prediction intervals were 37% narrower than persistence intervals at 72 hours. Propagating these tighter forecasts through orbital mechanics reduced along-track position uncertainty by 35% and the three-dimensional uncertainty ellipsoid volume by 91%.

With over 10,000 active satellites in low Earth orbit and constellations projected to exceed 100,000 within the decade, uncertainty-aware density forecasting offers a scalable, operationally deployable pathway to reducing collision risk during the extreme space weather events that threaten the long-term sustainability of the orbital environment.

**Detecting Microplastics In East Boston Beach Sediments Using Methylene Blue**

Bryan Ayala Angulo, Zach Saccardo

We chose to study microplastics because detecting microplastics is crucial for keeping our East Boston environment non-polluted, because there hasn't been enough research in East Boston on microplastics. Trash pollution is a significant problem in Eastie, and where trash is found, microplastics are also found. East Boston has a population of around 45,000 people, which can be a factor in the amount of microplastics that are littered all around the neighborhood. Microplastics are usually detected by using filtration, or sieving. Microplastic pollution usually comes from materials such as city dust, tires, synthetic textiles, and trash. Many areas in our environment have lots of microplastics that we haven't been able to detect yet. Doing something about this will spread awareness of our situation and help us find new ways to deal with microplastics. Methylene Blue is a cobalt-blue synthetic dye with a long history of highly specific medical applications, treating malaria or methemoglobinemia. In our project, we are using this solution to detect microplastics in different sediments by dying isolated samples of microplastics.

Acton-Boxborough Regional High

**Satellite Analysis and Visualization of Nitrogen Dioxide Columns during Cuba's October 2024 Blackout**

Andrew Wu

The October 2024 blackouts in Cuba were caused by the failure of the Antonio Guiteras power plant in Matanzas, Cuba. In addition to the economic effects, blackouts have consequences of decreasing notable air pollutants, such as nitrogen dioxide (NO2). Thermoelectric power plants and oil refineries are known to be major sources of such pollution; therefore, a failure of the electric grid and power outages can impact these point sources. This paper examines the use of Tropospheric Emissions: Monitoring of Pollution (TEMPO), a spaceborne spectrometer that monitors atmospheric trace gases over North America, to investigate the impact of the October 2024 blackouts on nitrogen dioxide columns in Cuba. First, quality control and assurance to remove artifacts in TEMPO NO2 observations with clouds and other factors was performed. Maps of nitrogen dioxide columns over Cuba were created, showing three time periods: before the blackout (10/13-10/17), during the blackout (10/18-10/22), and after the blackout (10/23-10/27). Next, four regions of Cuba, La Habana (Havana), Mariel, Santiago de Cuba, and Bahía de Nipe (Nipe Bay), were analyzed because these were regions with large power plants and high NO2 pollution, with each region showing different recovery rates. During a series of blackouts, columns showed a significant decrease compared to pre-blackout columns across all analyzed regions. Post-blackout columns showed a significant change compared to pre-blackout NO2 columns across all analyzed regions. Specifically, post-blackout NO2 columns decreased 9.6%, increased 32.0%, decreased 19.9%, and decreased 54.0% compared to pre-blackout across La Habana, Mariel, Santiago de Cuba, and Nipe Bay regions, respectively. In conclusion, thermoelectric plants and oil refineries are shown to be significant sources of NO2 pollution using the sensitivity of TEMPO to small changes in NO2 columns. A series of nationwide blackouts resulted in a decrease in NO2 columns, and different regions in Cuba showed varying rebound rates for NO2 columns.

Boston Latin School

**Impact of Battery Sizing and Operational Conditions on Degradation and Lifetime in Solar-Plus-Storage Energy Systems**

Aditya Tangella

The deployment of distributed energy storage and generation, notably with a focus on solar-plus-storage systems, is ever more recognized for its ability to enhance the resilience of power grids and encourage energy autonomy. Solar-plus-storage systems act to reduce dependence on traditional grid electricity while offering environmental and economic benefits through increased use of renewable energy resources and related cost savings. However, realizing the full benefits of solar-plus-storage systems requires addressing challenges with lithium-ion battery performance, including modeling capacity loss from real-world cycling patterns such as depth of discharge, C-rate, and battery chemistry. This study explores empirical data on battery operations to clarify the degradation mechanisms that are associated with usage patterns in solar energy systems. Using real battery cycling data from BatteryArchive and simulated solar generation and load profiles using real world data for Boston, MA, we analyzed lithium-ion battery degradation across different depths of discharge, C-rates, and chemistries, and considering energy usage, developed a degradation model for differently sized batteries in order to guide efforts to extend battery life. The results guide efforts to extend battery life and increase system reliability, thus enabling more accurate techno-economic assessments of distributed energy storage solutions. Future research activities will extend predictive modeling to a range of environmental and load conditions, incorporate calendar aging effects also critical to battery longevity, include machine learning approaches to the prognosis of battery health, and address lifecycle management and policy issues to support the sustainable and resilient deployment of distributed solar-plus-storage technologies.

**From Air to Earth: The Mineralization Method**

Keya Mahukiya

Addressing industrial pollution requires more than just reducing output; it requires capturing emissions before they ever reach the atmosphere. This project proposes a system that intercepts carbon dioxide directly at the smokestack using a vacuum-assisted filter. By passing factory exhaust through an amine solvent—a chemical "sponge"—the system selectively captures gas at the source. The captured gas is then transported through a network of pipes into an underground chamber filled with crushed reactive rocks. This setup triggers a process called carbon mineralization, a chemical reaction that permanently transforms the into solid, stable carbonate minerals. Unlike typical storage methods that keep carbon in a gaseous state, this approach effectively turns pollution into stone. This design demonstrates that by combining point-source capture with accelerated mineralization, we can create a permanent and leak-proof solution for industrial carbon storage, providing a realistic path toward cleaner manufacturing.

**Evaluating Low Cost Methods for Sterilizing Breast Pump Components in Low-Resource Settings**

Junyi Frenzel

Background: Breastfeeding provides infants with essential nutrients and antibodies and benefits infant and maternal health. However, it is not always possible to breastfeed due to medical reasons like prematurity or maternal illness, making pumping an important alternative to provide the baby the benefits of breast milk. In low-resource settings, limited access to electricity, clean water, and supplies can hinder safe breast milk storage and pump sanitation. Improper cleaning or storage can lead to bacterial contamination of breast milk, posing health risks to infants, which highlights the importance of effective sterilization methods. The purpose of this experiment was to find the most effective and low cost cleaning method to prevent bacteria growth in breast pump parts.
Methods: Seven different methods were tested: antimicrobial wipes (dapple baby), bleach (1.56% solution), vinegar (25% solution), microwave steam sterilization bag(steaming for 3 minutes), UV sterilization (10 minutes), boiling (5 minutes), and soap and warm water. Glo Germ, a fluorescent lotion used to simulate bacterial contamination, was applied to coat breast pump components that come into contact with breastmilk during pumping – the flange, valve, silicone and plastic backflow protector. UV light was used to fluoresce the Glo Germ, and photos were taken using standardized camera setup and settings before and after sterilization. ImageJ software was used to calculate fluorescence intensity within defined regions of interest in the digital images. Fluorescence values are reported in relative units and estimated the amount of microbial contamination. The percentage reduction in fluorescence was calculated to estimate the effectiveness of sterilization. Each experiment was repeated three times and the average of the three experiments compared.
Results: Of the seven methods, soap and water was the most effective with the highest percent reduction (24.2%) of simulated microbial contamination. Wipes and the steam bags had the next highest reductions of 21.7% and 16.2%, respectively. Boiling and bleach had 14.7% and 9.8% reduction respectively. Vinegar and UV were the least effective. In price analysis, for 1000 sterilizations, soap and water cost $29.40, wipes cost $199.60, and the steam bags $33.29. Other important considerations were the need for running water, electricity, and a microwave for the steam bags.
Conclusions: Soap and water is a recommended cleaning method by the CDC(Center for Disease Control) and was the most effective at reducing simulated microbial contamination. Boiling and bleach sterilization are also recommended by the CDC, however they were less effective. While wipes were found to be almost as successful as soap and water, they were very expensive. Overall, considering cost, effectiveness of sterilization, and CDC recommendations, the soap and water method was the most effective method for sterilization if running water is available.

Keywords:
Breastfeeding – Feeding an infant directly from a mother's breast, providing essential nutrients and immune protection.
Breast pump sanitation – The process of cleaning and disinfecting breast pump parts to make them safe for use.
Sterilization methods – Techniques used to remove or kill microorganisms on surfaces or equipment.
Low-resource settings – Environments with limited access to clean water, electricity, medical supplies, or equipment.
Infant health – The overall physical well-being and development of a baby.
Maternal health – The health and well-being of a mother, especially during and after pregnancy.
Bacterial contamination – The presence of harmful bacteria on surfaces or in substances like breast milk.
Breast milk storage – The process of safely collecting and keeping breast milk for later use.
Hygiene practices – Actions taken to maintain cleanliness and prevent the spread of germs.
Infection prevention – Measures used to reduce the risk of illness caused by microorganisms.
Soap and water cleaning – Washing items with soap and water to physically remove dirt and microbes.
Bleach sterilization – Using a diluted bleach solution to disinfect and kill microorganisms.
Vinegar cleaning – Using vinegar as a natural cleaning agent to reduce some microbes and residue.
UV sterilization – Using ultraviolet light to kill or inactivate microorganisms.
Steam sterilization – Using hot steam (such as in a microwave steam bag) to disinfect items.
Boiling sterilization – Placing items in boiling water to kill microorganisms through high heat.
Antimicrobial wipes – Pre-moistened wipes containing chemicals designed to kill or reduce bacteria.
Cost-effectiveness – A measure of how well a method works compared to how much it costs.
Glo Germ simulation – A method using a fluorescent substance to mimic the presence of germs for testing cleaning effectiveness.
Fluorescence analysis – Measuring light emitted by a substance (under UV light) to estimate contamination levels.
ImageJ analysis – Using ImageJ software to quantify visual data (like brightness) from images.
Microbial reduction – The decrease in the number of microorganisms after cleaning or sterilization.
Public health – The field focused on protecting and improving the health of communities and populations.

**Decoding the Gut-Heart Connection: Computational Analysis of Imidazole Propionate Interaction with Cage Proteins Retinol Binding Protein and Lipocalin in Atherosclerosis**

Geetika Seethammagari

Atherosclerosis is one of the leading causes of death worldwide, making it a major global health concern. Recent studies suggest that Imidazole Propionate (ImP), which is a molecule produced by gut bacteria, may worsen heart disease by promoting artery inflammation. This research investigates how ImP binds to Retinol Binding Protein (RBP) and Lipocalin, which are key to molecule transport in the body. Understanding these interactions is important because it could lead to new ways to detect, prevent, or treat cardiovascular diseases that affect millions of people globally.

**Tracking Inorganic Mercury in Marine Bacteria and Phytoplankton**

Kunio Saito, Jack Beardsley

Mercury is a potent neurotoxin. In its organic forms, it builds up in the bodies of marine organisms, with the concentration increasing at each tier of the marine food web. This concentration is caused by the phenomenon of bioaccumulation. When a predator eats an organism that contains organic mercury, that mercury makes its way into the body of the predator. The more of the prey that the predator eats, the more mercury concentration increases within the predator. This cycle repeats, leading to organisms at the top of the food web containing significantly higher concentrations of mercury in comparison to organisms at the bottom. A critical step in the process of bioaccumulation occurs when mercury first enters the food web. The objective of this project was to study the mechanisms of that entry point by identifying the proteins within marine microorganisms that absorb mercury into their cells. Identifying these proteins will lead to an improved understanding of the behavior of mercury within living organisms. Metalloproteomics, the method used in this experiment, is still not very widespread, and has lots of unexplored potential in the field of biochemical medical research. In Metalloproteomics, samples are analyzed using two-dimensional liquid chromatography. During this process, peptides are eluted into six 96-well plates, with the wells being organized on a gradient of cell size on one axis, and cell charge on the other. This well plate is then divided into a second well. These two well plates are then run on separate mass spectrometers, one to identify specific proteins, and the other to test levels of different metals within the proteins. Each well is tested for proteins and metals, allowing for a high resolution map of which proteins specific metals are bound to within the cell. Through the use of this method, mercury was discovered to be binding to similar proteins as the vital bioactive metal zinc. It was also discovered that these proteins were almost exclusively part of ribosomes, suggesting that mercury poisoning affects the protein synthesis function of cells.

**Aggressive Algae: Preventing Harmful Algal Blooms**

Michelle Zheng, Reagan Wray

Many freshwater lakes such as Lake Massapoag are plagued with blooms of harmful cyanobacteria in the summer months. Cyanobacteria is a type of algae also known as blue-green algae that is commonly found in lakes and other bodies of water. When there is an excess of cyanobacteria or a bloom, the algae releases harmful toxins which are dangerous to humans and animals alike. A major cause for these harmful blooms are high phosphorus levels caused by lake stratification due to higher temperatures in the summer and fertilizer runoff. This paper provides a look into how aluminum sulfate can be used to remove this excess phosphorus and prevent harmful algae growth. Our experiment involves Anabaena sp., triple super phosphate, and aluminum sulfate. We tested the growth of algae in beakers with neither compound, just triple super phosphate, and with both triple super phosphate and aluminum sulfate for tap and distilled water. We found that the algae in just tap water grew slightly, the algae in pure distilled water did not grow, the algae with triple super phosphate grew significantly, and the algae with both compounds did not grow. We concluded that aluminum sulfate was a successful treatment method to reduce phosphorus levels and therefore can be used in lakes to limit harmful algal blooms.

**Fluctuations of Condensed Counterions on B-DNA**

Joya Tendulkar

DNA is a highly charged polymer with a negatively charged phosphate sugar backbone. This backbone attracts positively charged ions--called counterions--to mitigate its repulsion. These counterions are tightly packed against the backbone, constantly providing a repulsion and tension that pulls the DNA lengthwise, resisting buckling or bending. The Onsager-Manning theory derives the equilibrium distribution of the condensed counterions around the backbone; however, it doesn't account for how these counterions may fluctuate from the equilibrium. This paper provides a free energy model that analyzes how variables such as salt concentration, counterion valence, and the Onsager-Manning linear charge density parameter affect these fluctuations, and thus the rigidity, as quantified through the persistence length of DNA. Then, through the screening parameter ($\kappa$), which reflects the ionic environment of the solution, this paper derives a quantitative relationship between fluctuations of counterion condensation and rigidity of the DNA backbone. Ultimately, we find that increasing salt concentration reduces counterion fluctuations and results in greater DNA rigidity.

**Observational Analysis of Antioxidant-Rich Food Consumption in Blood Glucose Management.**

Stephane Ofori, Angele Ofori

Type 2 diabetes mellitus (T2D) is a prevalent metabolic disorder characterized by impaired insulin sensitivity and chronic hyperglycemia. This observational study investigated the relationship between consumption of antioxidant-rich foods and blood glucose stability in individuals diagnosed with T2D—specifically, whether those who follow an antioxidant-focused diet experience reduced blood glucose fluctuations compared with those who follow a balanced diet. A two-part design was employed: Part I had participants complete an anonymous informational survey about their lifestyle, dietary patterns, and glucose management habits. Part II consisted of an optional 5-day log during which participants who wished to continue with the study self-recorded their pre- and post-meal blood glucose levels using their own monitoring devices. Factors such as sleep, exercise, stress, medication, and insulin use were also documented throughout. Only participants who submitted a valid informed consent form were included in the final quantitative analysis, as Phase II involved collecting personal health data (e.g., blood glucose levels). Results suggested a possible association between consuming antioxidant-rich foods and reduced postprandial glucose variability, with the antioxidant-focused participant demonstrating greater overall stability across the observation period. However, the conclusions are limited by a small sample size, significant confounding variables—including differential medication use—and an inconsistency in dietary self-identification observed in one participant. Therefore, further controlled studies with larger, matched samples are needed to establish causation.

Keywords: type 2 diabetes, antioxidants, oxidative stress, blood glucose management, postprandial glucose, dietary patterns

**VOCPAHs Blocker: An Eco-Friendly Solution for Suppression of Toxic Carbon Compound Emissions from Artificial Turf**

Jeongung Choi

Artificial turf—installed in more than 13,000 schools across the United States—poses an urgent yet underrecognized public health concern, as crumb rubber–based infill (CRbIs) releases neurotoxic volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAHs) under heat and UV exposure. This study aimed (1) to characterize the environmental and neurotoxic effects of CRbIs and (2) to engineer a cost-effective and environmentally sustainable VOCPAHs-Blocker capable of suppressing VOC and PAH emissions without removing existing turf. To assess CRbI toxicity, CRbIs were exposed to heat and ultraviolet radiation, and their leachates and evaporates were applied to lettuce seeds and human neuroblastoma SK-N-SH cells. CRbIs released approximately 30 times more toxic microparticles than water controls, reducing plant growth by 50% and neuronal cell viability by 30%, suggesting that continuous exposure to CRbIs may adversely affect surrounding ecosystems as well as the neurological development of adolescents who frequently use these fields. Next, a VOCPAHs-Blocker was engineered to inhibit toxic emissions from CRbIs. Cost-effective yet highly adsorptive materials—biochar, activated carbon, and zeolite—were selected and incorporated into agarose gel to produce small bead-like particles. The resulting VOCPAHs-Blocker reduced CRbI-derived toxic microparticles by approximately 35% and restored lettuce growth and neuronal cell viability to 95% and 100% of control levels, respectively. Overall, these findings establish the VOCPAHs-Blocker as a practical, scalable, and environmentally safe approach for mitigating CRbI-derived VOC and PAH exposure, offering a promising pathway to improve youth health and ecological safety while preserving the economic and performance benefits of artificial turf.

Lincoln-Sudbury Regional High

**A Hybrid Quantum-Classical Computational Study of Energetic and Conformational Differences in Amyloid-β variants**

Kushal Patil

The Arctic mutation (E22G) in the amyloid-beta protein causes early-onset Alzheimer's disease through accelerated protein aggregation, yet the electronic mechanisms underlying this phenotype remain unclear. Classical molecular dynamics captures structural changes but cannot account for quantum mechanical effects that may be crucial to aggregation propensity. We developed a hybrid quantum-classical computational pipeline to investigate whether electronic effects complement classical mechanisms in driving Arctic aggregation. We performed 110-nanosecond molecular dynamics simulations of Wild-Type and Arctic variants using GROMACS with the TIP3P water model, extracting the three lowest-energy conformers per variant. Structural analysis revealed that the Arctic mutation fundamentally reorganizes the protein backbone: Kolmogorov-Smirnov testing showed $p << 0.001$ on backbone dihedral angles ($\varphi$ and $\psi$), with Ramachandran plots visually confirming Arctic's favorability to β-sheet-favorable regions. One Arctic conformer (Set 2) reached 17.1% β-sheet occupancy versus Wild-Type at 2.5%, a 7-fold difference. To validate the electronic basis for this structural shift, we performed quantum mechanical calculations on all six conformers using four completely independent approaches: (1) VQE with UCCSD ansatz, (2) VQE with TwoLocal ansatz, (3) Active Space Transformer VQE on real IBM Marrakesh quantum hardware, and (4) B3LYP/def2-SVP density functional theory. All calculations used solvation for biological realism. All four methods showed Arctic electronic stabilization with similar magnitude (Kruskal-Wallis test: $p=0.53$, indicating no statistically significant difference between methods). Orbital isosurface visualization revealed that Arctic confines electron density in β-sheet-favorable geometries, while Wild-Type shows dispersed electronic distribution. Results align with recent cryo-EM structures (Yang et al., 2023) and cellular aggregation studies (Lu et al., 2018), suggesting that electronic effects act as a complementary stabilization mechanism to classical hydrogen bonding and electrostatic interactions. This work demonstrates that integrated quantum-classical approaches with real quantum hardware validation can identify disease-driving electronic signatures and provide a computational framework for quantum-accelerated drug discovery in neurodegenerative diseases.

**Investigations into Transduction Methods to Develop a Novel Wearable Biosensor to Detect Preclinical Allergic Reaction Signals**

Jay Lambert

Malden Catholic High School

**Enzymatic Degradation of Polylactic Acid**

Sophia Wan, Olivia Wan

Currently, the growth of 3D printed material, such as PLA is exponential, however, its growth rate is also increasing its long-term presence within landfills. In order for PLA to naturally degrade, it requires specific conditions and industrial recycling is not widely accessible. Our experiments test if there is a method to effectively combat these two issues, using lipase/foldase expressed in e.coli to degrade PLA into lactic acid through hydrolysis. While conducting experiments with live e.coli, lab safety and sterility were practiced with 70% isopropyl alcohol, Bunsen burners, and appropriate PPE. Each sample was suspended in PBS Buffer and incubated at 50°C for four weeks. While results signalled the degradation of PLA into lactic acid, there were minimal changes seen in the weight of the PLA, indicating low efficiency of the enzymes.

Newton Country Day School

**Buffering the Burn: Optimizing Sodium Bicarbonate Supplementation to Mitigate Exercise-induced Acidosis**

Catelyn Hickey, Johanna Jane-Leonardis

During high-intensity exercise, such as a 400 m sprint, the body demands ATP faster than oxygen can be supplied, forcing a shift to anaerobic glycolysis. This condition produces lactic acid, which quickly dissociates into lactate and hydrogen ions (H☐). When exercise intensity surpasses the body’s lactate threshold, H☐ accumulates faster than it can be cleared, lowering blood and muscle pH, contributing to metabolic acidosis, muscular fatigue, and impaired athletic performance. The primary extracellular buffering system in the blood, the bicarbonate–carbonic acid system, helps neutralize excess H☐, but physiological buffering capacity is limited during sustained anaerobic exercise. Ingestion of an exogenous buffer such as sodium bicarbonate increases extracellular bicarbonate concentration to enhance H☐ removal; however, optimal dosing remains unclear due to a relative physiological acid load. This project investigated how varying doses of sodium bicarbonate affect buffering capacity in a model of exercise-induced metabolic acidosis. The goal was to determine the optimal bicarbonate dose required to neutralize 20 mmol of lactic acid, based on physiological data from elite male 400 m runners. It was hypothesized that 22.00 g of sodium bicarbonate would most effectively resist pH change during simulated exponential acid accumulation. Extracellular fluid was modeled using aqueous sodium bicarbonate of varying concentrations. A diluted vinegar solution equivalent to 20 mmol of “lactic acid” was added exponentially over 45 seconds to simulate the non-linear acid accumulation during high-intensity exercise. Three experiments were conducted: an initial broad-range dosage test (0–45 g), a more structured dosage test (0–35 g in 5 g increments, three trials each), and a refined test (20–25 g in 1 g increments, three trials each). The pH of the sodium bicarbonate solution was continuously monitored, and mean ΔpH values were analyzed using descriptive statistics, marginal analysis, and a single-factor ANOVA. The structured dosage test demonstrated a statistically significant reduction in ΔpH with increasing bicarbonate concentration ($p < 0.001$) and revealed a plateau in buffering efficiency between 20 and 25 g. Although the refined 1g increment ANOVA did not confirm statistically significant differences among adjacent doses ($p > 0.05$), marginal analysis suggested diminishing returns beyond approximately 22–23 g, suggesting a maximum yield within the range of 23–24 g. To translate these findings into an application, an engineering component was incorporated. A 3D-printed die-plunger system was iteratively designed to compress the estimated optimal dosage, increasing the bicarbonate density to fit into a tablet compatible with enteric-coated capsules. This addressed limitations of existing supplementation methods, such as high pill burden and gastrointestinal distress. Overall, the results support the hypothesis within experimental uncertainty, with the observed optimal dosage range estimated at approximately 23–24 g, within 1–2 g of the predicted 22.00 g. These findings contribute to dose optimization strategies for sodium bicarbonate supplementation and provide a foundation for future investigation in female and non-elite athletic populations.

**Exploring Enzyme Kinetics of OATP1A2 to Aid in Drug Delivery Across the BBB**

Chaehyun Han

Abstract: The blood-brain barrier (BBB) restrict entry of more than 98% of small-molecule drugs into the central nervous system (CNS), posing a major challenge for neurotherapeutic development. Organic anion-transporting polypeptide 1A2 (OATP1A2), a sodium-independent uptake transporter highly expressed in BBB endothelial cells, represents a promising carrier-mediated pathway for drug delivery across the BBB. Despite its recognized role in BBB transport, quantitative kinetics data for OATP1A2 under physiologically relevant conditions remain limited. This study characterizes the concentration-dependent uptake of bromosulfophthalein (BSP), an OATP1A2 substrate, in HEK293 cells engineered to express the transporter using a UV-based spectrophotometric assay at pH 6.8 to approximate the endothelial microenvironment. Uptake rates were fitted to a Michaelis-Menten model by nonlinear regression, yielding apparent kinetic parameters of Km = 3.17 microM and Vmax = 47308 pmol/mg protein/min. The Km value is among the lowest reported for OATP1A2 substrates, suggesting high binding affinity and efficient transporter interaction under low-substrate conditions. Structural comparison with other OATP1A2 substrates, including estrone-3-sulfate, methotrexate, and pravastatin, suggests that the sulfate moiety of BSP may contribute to enhanced binding. These findings identify BSP as a high-affinity OATP1A2 substrate and support OATP1A2-mediated transport as a potential for improving CNS drug delivery.

Keywords: Blood-brain barrier (BBB); Michaelis-Menten kinetics; Organic anion-transporting polypeptide 1A2 (OATP1A2); bromosulfophthalein (BSP); carrier-mediated transport; transport kinetics; drug delivery.

**Tracking ALS Severity Through Data Analysis**

Aaliyah Correia

Amyotrophic Lateral Sclerosis (ALS), is a neurodegenerative disease that impacts about 1/100,000 individuals worldwide. Symptoms include difficulty speaking, behavioral changes, and weakened motor skills. This paper seeks to understand what variables might be indicative of an ALS diagnosis to improve the understanding of what may be negatively affecting the quality of life for ALS patients. After plotting four graphs from a dataset through RStudio against different variables, it was found that mental disorders had no notable relationship with the ALSFRS-R scores, while age and gender had a significant decrease effect on ALSFRS-R scores among patients that have certain traits. Older and male individuals, on average, had a lower score. It’s possible that this could be influenced by an unknown genetic or hormonal component, even if the disease was sporadic. These results and analysis should not be viewed as certain, as the dataset had a limited number of participants with mental disorders.

**AI-Driven Drug Repurposing for Glioblastoma Brain Cancer with Experimental Validation**

David Wang

Glioblastoma Multiforme (GBM) is the most common malignant primary brain tumor in adults. For many years, researchers have been trying to find new treatments for GBM; however, it requires much trial and error resulting in long and expensive drug development times. Since FDA-approved drugs already passed safety and toxicity, repurposing them for GBM could significantly reduce the time and cost traditionally associated with de novo drug development. This project thus seeks to create an artificial intelligence (AI)-based rapid method for identifying existing FDA-approved drugs that may be repurposed to treat GBM. It was hypothesized that small molecule inhibitors of genes significantly associated with GBM mortality rates -- determined by differential gene expression analyses of TCGA GBM patient samples -- would decrease glioblastoma cell viability. The computational strategy utilized molecular docking using Structure-Based Drug Design approaches. In particular, the Boltz-2 deep-learning enhanced docking program was used to predict the binding affinities of 347 existing FDA approved drug candidates to the TOP2A target protein. The docking computations were performed utilizing GPU acceleration to enable completion of all docking in approximately three days with high accuracy. Of the thirty best ranked compounds, additional filtering was performed using CNS Multiparameter Optimization (CNS-MPO) scores to assess blood-brain barrier permeability. The top three overall scored compounds from the model were then evaluated experimentally using the GL261 murine glioblastoma cell line. GL261 cells were cultured and exposed to each compound at one of three different concentrations (0.04, 0.2, and 1.0 μM). Cells were counted over a period of four days, which was then used to calculate the cell density. Each of the three compounds exhibited a significant ability to kill glioblastoma cells, with the observed decrease in cell density being both time- and dose-dependent. Importantly, the order of efficacy (Drug C > Drug A > Drug B) among the three compounds in killing glioblastoma cells was consistent with their predicted binding affinities. These findings support the use of an AI-powered approach as a reliable and rapid method for GBM drug discovery.

**The Effects of pH on the Reaction of Catalase**

Tiago Teixera, Eliana Monteiro, Suayane Lopes

The purpose of this lab is to investigate the effects of pH on the reaction rate of catalase. For our experiment, we hypothesized that if we increase the pH then the reaction rate of catalase will decrease because it denatures and the protein will lose its original shape not performing its job. To test this hypothesis we set up three tubes with hydrogen peroxide, we used pH of 3, pH of 7 and the last one pH of 9. We found that our hypothesis was right and pH 7 was the highest meaning it had the fastest reaction. This means our hypothesis was supported because pH 3 and pH 9 made the rate of catalase decrease. This is because acid denatures the protein and loses its original shape meaning it cannot perform its function .

**Physics-Informed Compositional Transformers for Predicting Viscosity of Protein Formulations from Amino Acid Sequences**

Vineeth Godavarti

Protein therapeutics are increasingly used for the treatment of diseases, such as cancer, diabetes, and auto-immune diseases. Additionally, subcutaneous delivery of therapeutic proteins offers several advantages over traditional intravenous administration, including greater patient convenience and lower overall costs. High-concentration protein formulations are essential to achieving the required dose for subcutaneous delivery; however, increasing protein concentration leads to elevated solution viscosity, limiting injectability and manufacturability. High protein viscosity is often identified late in development, leading to increased costs, substantial rework, and delays in delivering critical therapies to patients. Therefore, a reliable method to predict viscosity early in development would help avoid these setbacks and accelerate the path to patients. Previous models, such as DeepViscosity, have been developed to predict viscosity from a protein's amino acid sequence alone. In this study, a novel machine learning approach is described for predicting protein viscosity using features derived from three-dimensional (3-D) structure of proteins, in addition to sequence-derived features. A dataset of 151 therapeutic protein sequences was manually collated from published literature. 3-D protein structures were predicted from these sequences using AlphaFold, and 23 physicochemical and structural features were extracted to train a Random Forest classifier. Model performance was evaluated using nested cross-validation to minimize overfitting. As a sequence-based baseline, the DeepViscosity model achieved an accuracy of 79.50%, with a precision of 0.80, recall of 0.69, and F1-score of 0.74 for high-viscosity antibodies (>20 cP). In comparison, the 3-D structure-based Random Forest model achieved an accuracy of 82.75%, with improved recall of 0.80 and an F1-score of 0.75. Furthermore, SHAP analysis was conducted to interpret significance of various features; this revealed that of the ten most predictive features, six were derived from AlphaFold-predicted 3-D structures, with the most influential feature being charge cluster density, highlighting the importance of spatial electrostatic organization in viscosity behavior. These findings demonstrate that predicted 3-D protein structures provide mechanistically meaningful information beyond primary sequence alone, enabling earlier identification of viscosity liabilities and more efficient therapeutic protein development.

Key Words: therapeutics, proteins, viscosity, high-concentration, machine learning

**Novel Method for Remediation of Microplastics and Nanoplastics by Enzymatic Degradation**

Ronita Shukla

The ubiquitous presence of microplastic pollution from Arctic snow to infant blood has raised the specter of numerous life-threatening conditions including cancer, heart attacks and endocrine dysfunction. With its ability to bioaccumulate and biomagnify through the food chain, no other single problem poses such a threat to human health for this next generation of human life on Earth. Very few meaningful solutions have emerged for this major environmental threat beyond the desire to use less plastic.

This study evaluated whether enzymes can accelerate the degradation of representative micro- and nano-plastics under controlled conditions. Two case studies were performed. In Case Study I, poly(L-lactic acid) (PLLA) microplastics (used in 3D printing and medical devices) were screened against multiple enzymes; Proteinase K reduced suspension turbidity relative to controls and was further optimized for enzyme:substrate ratio, pH, and temperature. Lactic acid production (the expected hydrolysis product) was quantified over time using a Cedex HiRes metabolite analyzer, enabling estimation of reaction rates and fitting to a Michaelis–Menten model. In Case Study II, polysiloxane nanoplastics (10–100 nm) generated from high-flow pumping through silicone tubing were monitored by dynamic light scattering (DLS). Silicatein, an enzyme associated with sponge silica spicule formation, reduced the DLS nanoparticle peak signal and showed optimal activity near pH 7.5 and 36.5 °C. Together, these results demonstrate that enzyme-mediated digestion of both micro- and nano-plastics is feasible on laboratory timescales and supports future development of immobilized-enzyme reactors for wastewater treatment and broader protein-engineering efforts to expand substrate scope.

One of the other long term goals of this research is to identify suitable enzymes that can degrade microplastics and nanoplastics originating from multiple classes of plastic polymers. For example, some common plastic polymers include PET, polyethylene, polypropylene and poly vinyl chloride. Once suitable enzymes are identified by screening and shown to work experimentally in the lab, an in silico effort will be undertaken to engineer the enzyme sequence to further improve activity and enzyme reaction kinetics. This will then create a series of improved enzymes that can be applied for wastewater treatment and environmental remediation. Towards this goal, we employ the Maestro Bioluminate molecular modeling software from Schrodinger. This AI driven software allows the prediction and visualization of protein 3D structure from its primary sequence and was used to perform docking calculations for PETase with its substrate BHET (bis(2 hydroxyethyl) terephthalate. Docking calculations using the Glide tool within Bioluminate to calculate the binding energy returned a value of -4.5 kCal/mol for the native sequence. However, an engineered sequence identified in the literature (W159H, S238F) gave improved binding affinities of -6.0 kCal/mol. This effort was taken further by randomly mutating the amino acids in the binding site for the enzyme. An alternate sequence with W159H, S209F gave a further boost to the binding affinity resulting in -8.0 kCal/mol. This effort of reproducing and going beyond literature already existing on PETase validates the Bioluminate tool for molecular modeling. A similar effort will be undertaken in the future for Proteinase K with PLLA. Ultimately, it is anticipated that a series of engineered enzymes with fast kinetics will be identified for all major types of plastic pollutants.

**Peroxynitrite-Induced Suppression of NAD+ Dependent Lactate Dehydrogenase Activity in Alzheimer's Disease Pathogenesis**

Jay Bhatia, Robert Emanuel

Alzheimer's disease is the most common form of dementia, a progressive brain disorder that slowly destroys memory, thinking skills, and eventually, the ability to carry out daily tasks, leading to severe cognitive decline. Our goal is to study the role of peroxynitrites in Alzheimer's disease. We hypothesize that increased peroxynitrite formation in a neuroinflammed brain of an Alzheimer's patient, leads to a collapse of the astrocyte-neuron lactate shuttling system between astrocytes and neurons via direct inhibition of LDHB.

**HARMONIQ: A Novel Deep Learning Pipeline for the Discovery of Small Molecule Inhibitors of MAO-B as Therapies for Alzheimer's Disease**

Rory Hu

The design of small molecule inhibitors for monoamine oxidase B (MAO-B), a critical therapeutic target for Alzheimer's disease, poses significant challenges for improving potency, selectivity, and reversibility. To achieve these desirable drug properties, machine learning (ML) models have been developed to generate new molecular structures, expanding known chemical space. However, current models struggle to balance the synthesizability and novelty of generated molecules. To address this issue, this study introduces HARMONIQ, a novel deep reinforcement learning (RL) framework with ML-based quantitative structure-activity relationship (ML-QSAR) modeling, and applies it to create a promising new drug candidate for Alzheimer's disease. By integrating sequence-based and fragment-based drug generation through two stages of RL, HARMONIQ designs molecules that are both diverse and synthesizable. Furthermore, HARMONIQ is the first to introduce QSAR as an RL reward function to successfully optimize molecule selectivity. On average, the top 2000 inhibitors generated by HARMONIQ had a pIC50 of 6.48 and a docking score of -12.06 kcal/mol, achieving 24.5% improvement over the sequence-based model (REINVENT4) and 24.8% over the fragment-based model (FREED++). The HARMONIQ database, with 6461 RL-generated hit compounds, was further filtered alongside the Enamine database for pharmacokinetic, drug-likeness, and toxicological properties to find three lead candidates. The inhibition capacity of these leads was experimentally validated with fluorometric testing. The top HARMONIQ-generated molecule, (5-(3-(m-tolyl)propyl)thiophen-2-yl)methanamine, has been chemically verified as a potent MAO-B inhibitor and a promising drug candidate. In the future, HARMONIQ can be applied to other inhibitor targets.

Keywords: Alzheimer's disease (AD), monoamine oxidase B (MAO-B) inhibitors, drug discovery, reinforcement learning, quantitative structure-activity relationship, synthesis

Maimonides School

**Investigating Environmental DNA for Tetracycline Resistance Across Various Soil Sites**

Raya Sims

Falmouth Academy

**Enzymatic Degradation of Colored PET by Ideonella sakaiensis**

Hollis Oliver

Roughly 367 million tons of plastic are produced annually, and the mere 9% that gets recycled loses quality each time it is reclaimed, inevitably leading to waste. The bacterium Ideonella sakaiensis has recently been shown capable of enzymatically degrading polyethylene terephthalate (PET) plastic into monomers without deteriorating its usable properties, offering a potential solution to this problem as the resynthesized polymers can be recycled indefinitely. The purpose of this experiment was to test the effects of colorant additives in PET on the degradation of plastic by this bacterium. It was hypothesized that colorants would inhibit degradation. To test this, I. sakaiensis was incubated with samples of clear, transparent green, opaque white, opaque brown, and opaque yellow PET in a lean medium to encourage consumption of the plastic. The experiment lasted 19 days with optical density and mass measurements being taken throughout. The results showed that I. sakaiensis was able to more effectively proliferate in the clear and green treatments and that less cells were present in the three opaque treatments. By the end of the experiment, the uncolored PET had degraded the most, followed closely by transparent green, then by the opaques which did not exhibit large amounts of degradation and tracked closely with the negative control. These findings introduce the possibility that the presence of colorants does in fact inhibit the efficiency of PET biodegradation and that dyes are less likely to interfere with the process than pigments.

Tabor Academy

**Investigating Spirulina Platensis Potential as a Therapeutics to Chronic NF-κB's dysregulation in Neurodegenerative Disease (Animal Science)**

Andrea Lo

Neurodegenerative diseases, such as Alzheimer's disease, Parkinson's disease, amyotrophic lateral sclerosis, and Huntington's disease, affect over roughly 15% of the global population, with numbers projected to double in two decades. They are currently incurable and irreversible. Neuroinflammation is a key initiator and amplifier of neurodegenerative progression, with chronic NF-κB activation in glial cells driving neuronal dysfunction and cell loss.

However, direct targeting of this pathway can result in systemic toxicity. Although individual phytochemicals such as flavonoids have shown anti-inflammatory potential, their limited bioavailability has hindered clinical translation. Spirulina platensis, a microalga rich in carotenoids, polyphenols, and other bioactive compounds, may provide a synergistic and biologically accessible approach to modulating NF-κB activity.

This study uses a Drosophila melanogaster model of constitutive NF-κB activation (Relish 68) in glial cells, which mimics chronic neuroinflammation, to evaluate whether Spirulina platensis improves survival, behavioral, and morphological outcomes. Survival, negative geotaxis (climbing ability), and rough-eye phenotype were quantified to assess neuroprotective effects.

Dover-Sherborn Regional High

**Testing Miro & Milton Embryonic Impact on Myonuclear Spacing in Drosophila Melanogaster**

Pranav Kollipara

Muscle health is imperative to an organism's overall physiological health. At the cellular level, nuclei in myofibers are highly dynamic organelles that disperse evenly throughout the cell. However, in patients suffering from impaired muscular function, including age-related muscle-weakening or muscle disease, the spacing of these myonuclei is disrupted, implying that nuclear positioning is critical to muscular function. Similarly, mitochondria, typically distributed evenly throughout the cell, are also distributed unevenly in patients with impaired muscular function, implying that mitochondrial distribution is also critical to muscular function. While myonuclear spacing has been studied extensively, the impact of mitochondrial distribution on myonuclear spacing remains poorly understood. Thus, the study aimed to investigate whether an association between mitochondrial distribution and myonuclear spacing existed.

The GAL 4/UAS system was used in Drosophila Melanogaster to knock down Miro and Milton, two proteins that facilitate mitochondrial transport, in progeny via shRNA expressed embryonically. The progeny were dissected upon becoming L3 larvae. The VL3 and VL4 muscles of these larvae were subsequently imaged and analyzed through measurements of nuclear positioning, cell size, and cell width.

Comparing the ratio of actual internuclear distance to a computed maximal possible internuclear distance, the myonuclear spacing in the Milt RNAi and Miro RNAi group did not differ significantly from the control group ($p=0.982$ & $p=0.726$). However, cell size was significantly diminished in the Miro RNAi group ($p=0.000475$), suggesting Miro RNAi's role in mitochondrial transport affects cell size.

Berkshire School

**The Effects of Blue Light on the Proliferation, Differentiation, and Inflammatory Cytokine Secretion Functions of Keratinocytes**

Jasmine Shen

As technological devices continue to develop, our modern individuals' reliance on these electronics has continuously increased, leading to frequent exposure to blue light, specifically on our skin. While blue light has been applied to devices in acne treatment and circadian rhythm regulation, the long-term or wavelength-specific effects of blue light on skin cells remain controversial. For studying skin biology in vitro, human immortalized keratinocytes (HaCaT cells) are one of the most widely used cell culture models. In my research, we evaluated how HaCat differentiation can be induced in vitro with calcium. We compared pan-Keratin levels in cells exposed to UVB with and without calcium controls.

HaCaT cells were grown under various calcium conditions and exposed to different irradiance levels of UVB from an iPad, collecting timepoints at 24 hours and 48 hours, respectively. Cell differentiation was observed under a microscope, while images were captured at the respective time points for later comparison.  Cell differentiation was also assessed through Western blot analysis for the presence of keratin-10, a marker that is only expressed in differentiated cells.

Westfield High School

**Mycoremediation Utilizing Pleurotus ostreatus var. columbinus to Degrade Plastic**

Giovanni Santaniello

The accumulation of plastic waste poses a major threat to the environment today, and recent conclusions have suggested that Blue Oyster Mushrooms can solve this problem by degrading the synthetic polymers in specific plastic waste. The purpose of this project was to determine if Pleurotus ostreatus var. columbinus (Blue Oyster Mushroom), could degrade plastic materials. Throughout this project, the goal was to quantify the rate at which this degradation occurred.

Originally, it was hypothesized that PET plastic exposed to the mycelium would break down over an extended period of time. For the duration of the experiment, this plastic would be exposed to the mycelial network under measurable conditions. Throughout the experiment, limited mass measurements were recorded over 68 days. Applying the data collected, the degradation rates were calculated for the plastic and an accurate model was crafted predicting the degradation rate over a span of time.

Results of the experiment concluded that the plastic exposed to the mycelium had reduction in the overall mass calculation, while the plastic that was not exposed did not change in mass at all for the duration of the experiment. The models demonstrate the greater purpose and application of mushrooms, and their possible other applications to the real world instead of consumption. This highlights a different approach to controlling plastic waste on the Earth, while promoting a mutually benefitting system with Blue Oyster Mushrooms and the environment.

West Springfield High

**Natural versus Synthetic Skincare Products**

Yanellys Nunez, Batool Al Haron

This experiment investigated whether natural or synthetic skincare products were more effective at reducing bacterial growth. The hypothesis stated that synthetic skincare products would reduce bacterial growth more effectively because they contain antibacterial agents specifically designed to kill microbes. To test this, nutrient agar plates were prepared and inoculated with bacteria from probiotic gel capsules. Paper discs soaked in three natural products (honey, tea tree oil, and witch hazel) and three synthetic products (benzoyl peroxide, salicylic acid, and hypochlorous acid) were placed onto the agar. Sterile water was used as the control. The plates were incubated at 37°C for 24 hours, and bacterial growth was recorded using a scale of 1 (a little), 2 (some), and 3 (a lot). Results showed that synthetic products generally had less bacterial growth compared to natural products. Benzoyl peroxide and witch hazel showed minimal growth, while honey showed the most growth across all trials, similar to the control group. These findings supported the hypothesis that synthetic skincare products are more effective at reducing bacteria. This experiment demonstrates how product ingredients influence antibacterial effectiveness and provides scientific evidence to help consumers make informed skincare decisions.

Hopkins Academy

**The Effects of Sleep Deprivation on the Teenage Brain**

Ishika Patel, Haven Jones

Student examples and survey of effects of Lack of sleep

Newton Country Day School

**The Effectiveness of Natural versus Synthetic Anti-Fungal Preservatives when Deterring Blue Mold Growth on Pome Fruits**

Lucy Willett, Samantha Cho

Blue mold, caused mainly by Penicillium Expansum, is the most common mold among pome fruits. This experiment focuses on the fungus Penicillium Roqueforti, as it will provide similar results in a safer environment. The synthetic preservatives tested are pyrimethanil and Copper Fungicide, while the natural preservatives are lemon juice and thymol. The zone of inhibition test, otherwise known as the Kirby-Bauer test, was utilized in this experiment to determine the level of deterrence each preservative was able to achieve. Using thin paper discs submerged in a solution partially composed of a particular preservative, the amount of mold growth inhibited by each variable was documented. The concentration of each preservative was also taken into consideration, as a primary goal of this experiment was to best recreate 'in the field' conditions' and each variable's potency in regards to the amount of Penicillium Roqueforti being distributed to each plate. Using both water and ethanol, each preservative was diluted to better the quality of the experiment's results. Post testing trials, pyrimethanil, a synthetic preservative, and thymol, a natural preservative, were the only two variables that produced measurable results. Though both showed noticeable results, pyrimethanil prevented mold growth at a significantly greater amount than thymol, copper fungicide, etc. All other variables were unable to prohibit mold growth, instead allowing for the Blue Mold to grow overtop of the disc. After 4 trials of testing, it was concluded that pyrimethanil is the most effective among the preservatives in this experiment, with all other experimental groups providing no results but thymol. Due to the small number of variables that had zones of inhibition, it is difficult to determine whether synthetic or natural preservatives work best.

Wellesley Sr High

**Phospholipid Deletion Alters Lipid Metabolism, Growth, and Stress Response in Mycobacterium smegmatis**

Kornkanya Charoensiddhi

Mycobacterium tuberculosis, the causative agent of tuberculosis, has become resistant to many traditional antibiotics due to its thick, lipid-rich membrane. Phosphatidylethanolamine (PE) is a key phospholipid within the mycobacterial membrane and is essential for maintaining the cell's stability and function. This study examines the role of phosphatidylserine decarboxylase (Psd) in PE synthesis by investigating the pssA-psd operon, which encodes for sequential enzymes in the final steps of PE synthesis. The deletion of psd was expected to disrupt PE production, altering membrane lipid composition and impairing cellular growth. A psd deletion mutant and complement strain were generated and compared against the wild-type strain using growth assays, environmental stress tests, and lipidomic analysis. Lipidomic analysis also revealed a complete loss of PE in the mutant. The mutant also exhibited reduced growth and increased sensitivity to environmental stress, indicating impaired membrane function. Furthermore, complementation did not restore PE production, highlighting the cell's dependency on the entire operon for PE synthesis. These findings demonstrate that Psd is critical for maintaining membrane lipid balance in mycobacteria, highlighting the enzyme as a target for anti-tubercular drug development. Structural analysis of Psd using Alphafold2 and ChimeraX revealed that the catalytic Ser231 serine group is situated within a deep, hydrophobic binding pocket. Based on the surrounding residue environment, we conclude that an ideal inhibitor would be a lipophilic small molecule featuring a planar ring structure (to stack with Phe207) and positive functional groups (to target Glu230). Such a drug would effectively block PE production, providing a potent therapeutic strategy for targeting tuberculosis.

KEYWORDS: Mycobacterium tuberculosis, phosphatidylserine decarboxylase (Psd), phosphatidylethanolamine (PE), psd-pssA operon, lipidomics, binding pocket analysis, tuberculosis therapeutics

Newton Country Day School

**Using a Wound-Healing Model in Drosophila melanogaster to Examine Plasmatocyte Migration and Cell Division Under Different Microenvironmental Conditions**

Isabelle Martin, Erin Bourque

How do differing levels of pH at a wound-site affect the migration of plasmocytes and cell division in Drosophila melanogaster? Plasmatocytes, the functional equivalent of human macrophages in Drosophila melanogaster, play a vital role in phagocytosis and wound healing. The study of plasmatocytes was chosen largely because M2 macrophages, when activated, promote tumor progression and metastasis. A puncture wound healing model was used to prompt cell division and study the effect of pH microenvironments on plasmatocyte migration. The hypothesis for the experiment was: when Drosophila melanogaster are exposed to an acidic microenvironment, there will be faster wound healing and more macrophages recruited to the site than there will be when they are exposed to a neutral microenvironment. Two different groups of fruit fly larvae were exposed to pH 7 or pH 4 solution for two minutes then punctured. The fluorescent plasmatocytes in the larvae were imaged for an hour in ten minute intervals. Although conclusive results cannot be drawn from the experiment, data suggests that the hypothesis was supported. The rate of plasmatocyte migration to the wound site was faster in an acidic microenvironment (pH 4) than in the neutral microenvironment (pH 7). One plasmatocyte in the pH 4 condition moved towards the wound at a rate of 28μm per minute whereas one plasmatocyte in the pH 7 condition moved towards the wound at a rate of 8μm per minute. Additionally, there appeared to be a higher plasmatocyte concentration surrounding the wound sites in the acidic (pH 4) rather than the neutral (pH 7) microenvironment. This data suggests that a neutralized microenvironment would slow the spread of cancerous division allowing more time for treatments to target the cells.

**Insights into KMT2D Mutations in Colorectal Cancer: Implications for Immunotherapy Response and Targeted Therapeutic Strategies**

Anvi Sarmah

Colorectal cancer (CRC) is the third most common cancer and the second leading cause of cancer-related deaths worldwide. CRC development is primarily driven by two mechanisms of genomic instability: chromosomal instability (CIN) and microsatellite instability (MSI). MSI occurs in 13-16% of CRC cases, with MSI-high (MSI-H) tumors arising from defects in the DNA mismatch repair (MMR) system. While MSI-H tumors respond to immune checkpoint inhibitors due to their increased immunogenicity, responses vary significantly among patients, highlighting the need for better predictive biomarkers. Previously, using CRC patient datasets in cBioPortal, I found KMT2D, a histone methyltransferase involved in chromatin regulation, as the most frequently mutated gene, which co-occurs with classical MSI-H gene mutations, including MLH1, MSH2, and MSH6. Tumors with KMT2D mutations exhibited elevated PD1/PD-L1 immune checkpoint expression and increased immune cell infiltration, suggesting an inflamed tumor microenvironment. In contrast, MSI-H tumors harboring GNAS mutations, mutually exclusive with KMT2D, are associated with reduced immune cell infiltration and a more immune-cold tumor phenotype. These findings indicate distinct immune states within MSI-H tumors and support KMT2D mutation status as a potential biomarker to improve immunotherapy stratification in MSI-H colorectal cancer.

In this study, I evaluated how KMT2D mutation status affects immunotherapy response and the tumor immune landscape. Survival analysis showed slightly improved outcomes in pan-cancer immunotherapy cohorts, but not in MSI-H CRC, indicating context-dependent effects. Immune deconvolution using CIBERSORTx confirmed increased infiltration of cytotoxic T cells, CD4☐ memory T cells, and M1 macrophages in KMT2D-mutant tumors. Additionally, mRNA expression analysis using cBioPortal demonstrated upregulation of immune activation genes, including CD8A, GZMB, PRF1, IFNG, CXCL9, and CXCL10, as well as antigen-presenting genes TAP1 and TAP2, supporting an immune-active microenvironment in KMT2D-mutant tumors. However, elevated expression of immunosuppressive and T-cell exhaustion markers such as FOXP3, CCR8, TGFB1, LAG3, and TIGIT suggests the presence of a functionally suppressed tumor microenvironment. These findings indicate an immune-active but functionally suppressed tumor microenvironment. To identify mechanisms behind this, gene dependency and synthetic lethality analyses were performed, identifying KDM6A, a chromatin-modifying histone demethylase, as a key co-dependent partner of KMT2D, with context-specific essentiality in KMT2D-mutant tumors. Notably, KMT2D and KDM6A co-mutant tumors demonstrated improved disease-free survival and a reprogrammed immune landscape characterized by reduced regulatory T-cell signatures and enhanced cytotoxic and innate immune activity. These findings suggest that KMT2D mutations create an immunologically “hot” microenvironment, but immune suppression limits efficacy, and that targeting KDM6A may represent a synthetic-lethal vulnerability that enhances anti-tumor immunity. Overall, integrating MSI status with KMT2D mutation and KDM6A dependency may improve patient stratification and support the development of more effective combination immunotherapies for CRC.

Newton North High

**Gene Expression in Different Breast Cancers Cells**

Hongyi Ni

Breast cancer includes diverse subtypes, such as triple-negative breast cancer (TNBC) and hormone-receptor-positive cancers, each with distinct molecular profiles. This study aimed to identify genes with significantly higher expression in TNBC compared to hormone-receptor-positive cell lines to highlight potential therapeutic targets. Using gene expression data from the Broad Institute DepMap database and analyzing the data in RStudio, t-tests revealed that GSTP1, AKR1B1, MSN, IGF2BP2, and CCDC82, among others, showed significantly higher expression in TNBC cell lines compared to hormone-receptor-positive cell lines. These five genes demonstrated the strongest statistical significance. The results suggest that these genes may contribute to TNBC pathology and represent promising candidates for targeted therapeutics.

North Attleboro High

**Machine Learning–Based Prediction of Phage–Host Interactions and Coverage Optimization Using Genomic Receptor and Defense Features Against the Escherichia Genus**

Aru Sharma

The rapid rise of antimicrobial resistance has reduced the effectiveness of conventional antibiotics, creating an urgent need for alternative antimicrobial strategies. Bacteriophage therapy offers high specificity against bacterial pathogens, but its clinical application is limited by the difficulty of selecting phages that provide broad and reliable coverage across genetically diverse bacterial populations. Suitable design of phage cocktails remains a major challenge. This study evaluated whether ML models trained on bacterial genomic features could predict phage infectivity and guide the construction of phage cocktails that outperform random selection in lytic coverage across strains from the Escherichia genus. A machine□learning□guided framework was developed using publicly available phage–host interaction data from a Nature Scientific Reports dataset. Genomic predictors included outer membrane protein (OMP) profiles and intracellular defense system counts extracted from supplementary tables. Using a 80/20 train and test split, logistic regression and random forest models were trained to predict binary infectivity outcomes for three phages (CLB_P2, 536_P7, and 536_P9), and model performance was evaluated using ROC–AUC, confusion matrices, and 5□fold cross□validation. Although the predictive signal was weak, CLB_P2 achieved the strongest performance (ROC–AUC = 0.6084 for logistic regression; 0.5840 for random forest), while 536_P7 and 536_P9 exhibited minimal or near□random predictability. Predicted infectivity matrices were used to construct phage cocktails using OR□logic and a greedy optimization strategy. Individual phages lysed 53.00–60.75% of strains, whereas optimized multi□phage cocktails achieved up to 80.25% coverage, outperforming all single and pairwise combinations. A 5,000-iteration Monte Carlo simulation revealed that randomized “idealized” phages achieved higher artificial coverage (mean = 0.9261) due to the removal of biological constraints, underscoring the limiting effects of shared receptors and overlapping defense systems in realistic phage combinations. These results indicate that while the selected genomic features alone are insufficient for strong single□phage prediction, machine□learning□guided cocktail optimization can enhance lytic coverage. Future work should incorporate additional genomic determinants and larger phage panels to improve predictive accuracy and support clinical translation.

Foxborough Regional Charter School

**Evaluating the Efficacy of Natural Agents for Preventing Aggregation and Promoting Dissolution in Calcium Oxalate Kidney Stones**

Kyrillos Mourad

Calcium oxalate kidney stones account for approximately 70–80% of all kidney stones and can cause significant pain and complications. This study evaluated the effectiveness of three natural plant extracts—Garcinia cambogia, Plantago major, and Boerhavia diffusa—in promoting dissolution and preventing aggregation of calcium oxalate crystals in vitro. Synthetic calcium oxalate crystals were prepared through a precipitation reaction between calcium chloride and sodium oxalate and were then exposed to aqueous solutions of each extract at a concentration of 10 mg/mL. Crystals were incubated at 37 °C for 72 hours, after which changes in crystal mass and inter-crystal distance were measured to assess dissolution and aggregation. Results showed that Garcinia cambogia produced the greatest reduction in crystal mass (−18.63%) and increased the average distance between crystals by 15%, indicating both dissolution and anti-aggregation effects. Plantago major demonstrated moderate dissolution (−9.01%), while Boerhavia diffusa showed smaller effects (−4.47%), and the control group showed minimal change (−0.50%). These findings suggest that plant-derived compounds, particularly Garcinia cambogia, may offer potential as complementary approaches for preventing calcium oxalate kidney stone formation and promoting dissolution.

Shrewsbury Sr High

**Functional Analysis of Attenuated Amyloid-β Neurotoxicity via Pan-Neuronal Hsp104 Co-Expression Mediated by QUAS/57C10 and GAL4/UAS in Drosophila melanogaster**

Samad Udaipurwala

Alzheimer's disease kills neurons through accumulation of toxic amyloid-β42 (Aβ42) protein aggregates, yet current treatments only mask symptoms without stopping neurodegeneration. This study investigates whether Hsp104, a yeast-derived protein disaggregase, can rescue Aβ42-induced toxicity by disassembling intracellular aggregates. We hypothesized that pan-neuronal co-expression of Hsp104 with human Aβ42 in Drosophila melanogaster would mitigate neurotoxicity and behavioral dysfunction compared to Aβ42 alone. Using dual transgenic systems (GAL4/UAS and QUAS/57C10), we generated flies expressing either Aβ42 or Aβ42+Hsp104 in all neurons. We assessed rescue efficacy through three behavioral assays: negative geotaxis (climbing ability), Kaplan-Meier survival analysis, and Drosophila Activity Monitor sleep and circadian rhythm monitoring across young and old flies, both sexes. Results demonstrated complete Hsp104 rescue in motor function (maintained wild-type climbing across 40 days, $F=42.5$, $p<0.0001$) and lifespan (>95% survival vs 0% in Aβ42 alone; Log-Rank $\chi^2=67.2$, $p<0.0001$, representing 95% mortality risk reduction). Critically, circadian rhythm parameters (rhythmicity index, period) were rescued. However, Hsp104 had circuit-specificity to rescue Aβ42-induced sleep disruption and fragmentation (35-49% reduction persisting in both genotypes, $p<0.0001$), revealing circuit-specific therapeutic selectivity. This identifies clock neurons as uniquely vulnerable to Aβ42 aggregation. Future work will employ cell-type-specific drivers targeting Hsp104 exclusively to circadian neurons and use RNA-seq to identify mechanisms, ultimately enabling development of circuit-specific Alzheimer's therapeutics.

Westborough High

**Using Senolytics to Rescue Cognitive Function in a Mouse Model of Alzheimer’s Disease Through Selective Cell-Type Targeting**

Arushi Vora

Alzheimer’s disease is a neurodegenerative disorder that impacts over 7 million Americans and is one of the leading causes of death. Recent studies have linked neurodegeneration with accumulation of senescent cells. Cells become senescent due to stress and aging, which alters their function and leads to the secretion of harmful factors that exacerbate neurodegeneration. Preclinical research suggests that targeted clearance of senescent cells using senolytics may halt or reverse cognitive decline in mice by selectively eliminating senescent cells. Although senolytics are currently being incorporated into clinical trials as a potential therapy for Alzheimer’s disease, the specific cell types and brain regions targeted by senolytics remain unknown. This study aimed to explore the prospect of using ABT-737 for targeted, cell-type-specific senescent cell clearance in the hippocampus. The 5xFAD Alzheimer’s mouse model was used to test the impact of ABT-737 on expression of the senescence-associated genes P21 and P16. ABT-737 improved memory performance and immunohistochemical analysis suggests that the treatment reduced the density of P21+ and P16+ cells in the hippocampus, providing confirmation of prior spatial transcriptomics analysis. Additionally, ABT-737 did not reduce the density of P21+ and P16+ microglia, indicating potential microglial resistance to the treatment. The density of P21+ and P16+ endothelial cells and astrocytes following treatment decreased to levels akin to the wildtype mice. There was no observed effect of ABT-737 on P21 expression among neurons. Additional analysis is needed to investigate the impact of senolytics on oligodendrocyte lineage cells. Overall, these results indicate that ABT-737 is able to target different senescent cell populations, suggesting that senolytic therapies may improve neurological outcomes by selectively targeting specific senescent cell populations in Alzheimer’s disease. Furthermore, this points to a role of senescent astrocytes and endothelial cells in disrupting working memory function. Current and future research will focus on analyzing cFos levels among hippocampal neurons as a marker of neuronal activity, measuring CXCL10 levels among astrocytes, and analyzing senescence among oligodendrocytes and OPCs.

Keywords: Alzheimer’s disease, cellular senescence, ABT-737, p21, p16, astrocytes, endothelial cells, neurons, microglia, hippocampus

Winchester High School

**Effect of Mushroom-Bacteria Co-culture on the Antimicrobial Effects of Mushrooms**

Eunice Wang

Edible mushrooms have been used medicinally for their health benefits, including anti-inflammatory, anti-caner, immunity booster and antimicrobial properties. Commercial mushrooms are often grown in sterilized conditions to limit competition and optimize growth. This study aims to test the antimicrobial activities of various edible mushrooms from markets and see if co-culturing them with bacteria will create stronger anti-bacterial properties and further elevate its benefits on human health. Ethanol and water extracts from four common edible mushrooms,  Hericium erinaceus (lion's mane), Pleurotus ostreatus (oyster mushroom), Lentinula edodes (Shiitake) and Agaricus bisporus (button mushroom) were tested against Escherichia coli MG1655, Pseudomonas aeruginosa PAO1, Staphylococcus aureus HG003, and Bacillus subtilis NCIB 3610. Shiitake water extract showcased strong antimicrobial effects against all four tested pathogenic bacteria, the fungal pathogen of Candida albicans, and the corresponding biofilms. The antimicrobials in Shiitake water extract are heat labile, work in weak acidic conditions, and contain proteins / peptides and polysaccharides, and many other components. Preliminary genome sequencing analysis of the B. subtilis mutants with increased resistance to the Shiitake water extract generated a list of mutated genes which largely clustered into three categories: DNA replication / repair, SPβ prophage, and type II toxin / antitoxin (TA) modules, including genes encoding sporulation killing factor (SKF), autolycin and holins. The combination of bacterial Live /Dead assay and CFU counting of B. subtilis treated by shiitake water extract indicated that a fraction of the killings were caused by cell envelope damages. The ethanol extracts of all mushrooms displayed weak antimicrobial effects against B. subtilis. The fast growing lion’s mane mushroom and oyster mushroom whose extracts exhibited little or no antimicrobial effects were co-cultured with the four bacteria, respectively. The co-cultures boosted oyster mushroom growth, especially by B. subtilis or P. aeruginosa. Water extracts of the co-cultured mushroom did not show improved mushroom antimicrobial activities. As for the ethanol extracts, all co-cultured oyster mushrooms exhibited higher antimicrobial properties against E. coli and B.subtilis. The co-culture of lion's mane with S. aureus did not increase its antimicrobial effect against P. aeruginosa, but increased the effects against S.aureus,  E.coli and B.subtilis, particularly B.subtilis. This study demonstrated that co-culturing mushrooms with bacteria enhances the health benefit of the edible mushrooms.

Key words: antimicrobials, edible mushrooms, co-culture, bacteria

Hopkinton High

**Effect of a Weak Electric Field on Drug-Like Molecular Transport Across a Model Blood-Brain Barrier.**

Sahaj Pogula, Arjun Mehta

This experiment investigated how the number of membrane layers affects the movement of dye when an electrical force is applied. The purpose was to model how the Blood–Brain Barrier controls what substances can enter the brain. It was hypothesized that increasing the number of membrane layers would decrease the distance the dye travels. In the experiment, dialysis membranes were arranged in 0, 1, and 2 layers, and an electrical voltage was applied to move dye across the barrier. The distance the dye traveled was measured in each trial. The results showed that dye moved the farthest when there were no membrane layers and the least when two layers were used. This demonstrates that thicker barriers reduce the movement of molecules, even when an electrical force is applied. The experiment supports the idea that biological barriers like the Blood–Brain Barrier help regulate which substances can enter the brain.

Wachusett Regional High

**Modeling Celiac Immune Activity in C. elegans**

Megan Jeffcoat

Celiac disease affects approximately 1% of the global population, yet 30–60% of patients continue experiencing symptoms despite strict adherence to a gluten-free diet, the only known treatment. A 2025 Nature Immunology study introduced the idea of "immune scarring" (persistent immune activation remaining after the dietary trigger is removed) as a likely explanation, though this phenomenon remains understudied. This project asked whether Caenorhabditis elegans could serve as a viable model organism for studying celiac disease by investigating two symptoms of the condition: gut barrier dysfunction and immune scarring. Wildtype worms were exposed to Pseudomonas aeruginosa PA14 for 0, 6, 12, or 18 hours to simulate gut inflammatory insult, then either immediately analyzed (reference group) or transferred to standard food for 48 hours before analysis (recovery group). Gut permeability was quantified using GFP-labeled food and fluorescence imaging in Fiji/ImageJ, and immune gene expression was measured by qPCR targeting irg-1, nlp-29, and pals-5. Results showed that gut barrier damage worsened dose-dependently after recovery, peaking at 15.7× greater permeability in the 18hr recovery group. Epithelial immune genes nlp-29 and pals-5 remained significantly elevated in recovery despite pathogen removal, indicating damage-driven rather than pathogen-driven persistent activation consistent with immune scarring. The acute alarm gene irg-1 resolved upon pathogen removal, confirming the worm responded authentically to the inflammatory insult. Unexpectedly, the 12hr, not 18hr exposure group, produced the most robust immune gene persistence. These findings support the use of C. elegans as a model for studying celiac disease and establish the 12hr recovery model as a platform for future research in celiac and immune scarring.

**How Does Microbe Type Affect the Electrical Output of a Microbial Fuel Cell?**

Justin Walsh

Shrewsbury Sr High

**Novel Programmable Metal-Organic Frameworks Synthesis for Airborne Neurotropic Viruses and Antiviral Immune Pathogenic Resistance in Caenorhabditis elegans using Vitelline Membranes**

Jayaratna Deshamouni

Airborne Neurotropic Viruses (ANVs) are emergent invasive neuropathogens that affect around 300–500 million lives worldwide. Despite advances in vaccine therapeutics, < 2% of over 1,400 human viral pathogens are medicinally treatable. The complex molecular mechanisms of ANV cause blood-brain barrier (BBB) dysfunction and toll-like receptor-3 (TLR-3) gene-mediated neuroinflammation, resulting in proteotoxicity and dysfunction of the DAF-16/FOXO3 longevity pathway. This highlights neurotropic transcriptomic sequestration as a critical area for research. This study investigates how a novel synthesized DNA Aptamer–Eggshell Vitelline Membrane Metal-Organic Framework (MOF) (ANV-Probe) can influence DAF-16/FOXO3 stress-response signaling markers associated with airborne neurotropism in a Caenorhabditis elegans model. This study assesses several ANV symptoms including neuro-muscular impairment, cytotoxicity, germline stress, and viral titre. ANV was induced in C. elegans using aerial fluorescent viral microspheres, and several MOF nano-therapeutic groups were incorporated into the nematode's E.coli food source. Molecular assays (Viral MFI) and physiological assays (locomotion, longevity, fecundity) (n=20, N=320), were conducted to assess the efficacy of the ANV-Probe in modulating DAF-16/FOXO3 signaling markers for systemic health. Results suggest highly significant sub-nanomolar pathogenic absorption, enhanced homeostatic restoration, and upregulated transcriptomic regulation. These findings discovered that administering the ANV-Probe can upregulate DAF-16/FOXO3 signaling markers and enhance physiological phenotypes in C. elegans compared to inefficient therapeutics, due to high-affinity sequestration of airborne neurotropic agents. Bioinformatic simulations of multi-organal ANV-related diseases revealed superior deployable human efficacy. This is the first study to use an avian-inspired, programmable, waste-derived MOF (ANV-Probe) for DAF-16/FOXO3 signaling as a viable therapeutic target for mitigating viral-induced neurodegeneration and multi-organ diseases. Future research and applications include low-cost deployment of the ANV-Probe through intravenous dosing, in-vivo validation in vertebrate mammalian models, and applying RT-qPCR and Vero/Neuro-2a plaque assays to confirm inhibition. Key Words: Airborne Neurotropic Viruses, Metal-Organic Frameworks, DNA-Aptamer, Eggshell Vitelline Membrane, Caenorhabditis Elegans, DAF-16/FOXO3 Signaling

**Aluminum Trichloride Induced AD Model in Zebrafish Larvae Exhibits Neurological Impairment**

Sophie Zhixuan Qiao

Alzheimer's disease (AD) is a widespread disease exhibiting neural system damage, including myelin damage, oligodendrocyte damage, and apoptotic neural cell death. Zebrafish larvae are a model organism well-suited for drug screening and have multiple established AD models. Of these models, the AlCl3 induced AD model in zebrafish larvae is a common pharmaceutical model in early-stage drug screening. However, previous researchers have used a purely behavioral evaluation with this model, which does not reveal how a drug interacts with the underlying biological processes of neurodegeneration. Therefore, in this study, this AD model was induced with AlCl3 (38.6 μg/mL), and neurodegeneration hallmarks were assessed. Dil staining was used to observe neural system damage, further on sox10 expression levels in Tg:Sox10:Gal4-UAS: Tdtomato zebrafish were used to observe oligodendrocyte degeneration, and caspase 3 immunofluorescence was used to evaluate apoptotic neural cell death. The above results show significant damage to the neural system in the AlCl3 induced AD model in zebrafish larvae. Ultimately, by evaluating multiple hallmarks of neurodegeneration, this study accelerates drug screening and increases the accuracy of identifying therapeutic candidates with greater potential for treating Alzheimer's disease.

Keywords: Alzheimer's disease; zebrafish larvae; AlCl3; oligodendrocyte; apoptotic neural cell death

Wachusett Regional High

**Journey to an Unforgettable Future: The Effects of Lithium Nitrate on Drosophila Learning and Memory**

Nirelis Aponte-Garcia

Lithium (Li) is a known mood-stabilizer, neuroprotector, used to treat bipolar disease. In a study by Aron et al. in Nature (2025), it was shown that mice with a lithium deficiency in the prefrontal cortex had increased deposition of Amyloid-beta 42 (Aβ42) and phospho-tau proteins, which are known to cause Alzheimer's Disease. The hypothesis was that increasing the dose of lithium, will decrease the time to learn and recall behavior of adult Drosophila melanogaster. Three experimental groups of adult flies were exposed for 24 hours to three concentrations of lithium nitrate solution (0.5 mg/mL, 1 mg/mL, and 1.5 mg/mL). After the exposure, five flies were transferred to the test tube, covered with a cotton ball and added 10 drops of apple cider vinegar to attract them upwards. A negative geotaxis assay was conducted to measure the time it took to avoid climbing up (learning phase) followed by a 5-minute behavior recall test. The statistical analysis was performed with a T Test, a p value of 0.05 was considered statistically significant. The results show a statistically significant trend that all doses of lithium decrease the learning time. The recall of behavior after 5-minutes was maintained on all study groups but was only statistically significant on the 1.0 mg/mL. In conclusion, lithium increased learning and recall of behaviors independently of the dose in Drosophila melanogaster. These results suggest that lithium indeed may improve outcomes in patients suffering from dementia or other learning disabilities.

Lexington High

**Molecular Simulation of Synaptic Protein Liquid–Liquid Phase Separation: Modeling CaMKII and PSD-95 with Mpipi Coarse-Grained Model**

Yeseo Kim

Liquid–Liquid Phase Separation (LLPS) organizes proteins at synapses and helps regulate learning and memory by forming dynamic, membrane-free compartments in the postsynaptic density, which lacks a surrounding membrane. While many LLPS studies focus on intrinsically disordered regions or simplified systems, less is known about how larger, folded synaptic proteins behave in computational models that exhibit phase separation. In this study, I used the Mpipi coarse-grained model to extend LLPS simulations to folded synaptic proteins with known crystal structures, including the scaffold protein PSD-95 and the kinase CaMKII in different activation states, across temperature and concentration ranges. I examined how protein size, structure, and activation influence phase separation behavior. The active CaMKII kinase domain showed the clearest LLPS at intermediate temperatures, but not at higher temperatures tested. In contrast, PSD-95 alone, inactive CaMKII, the CaMKII oligomerization domain, and the CaMKII linker region did not form stable condensates under the same analysis. In two-protein simulations, active CaMKII exhibited LLPS while PSD-95 remained largely diffuse, suggesting that additional interaction domains or more complete postsynaptic assemblies may be required for stable co-condensation in this simplified system. Overall, this work demonstrates that coarse-grained models, such as Mpipi, can be applied to folded synaptic proteins with known structures to test how activation state and multivalency shape condensate formation. Because synaptic function requires a balance between stability and reversibility, shifts toward either weaker or overly stable condensates may impair synaptic remodeling and contribute to dysfunction associated with neurodegenerative diseases such as Alzheimer's.

Lexington High

**The Hive Mind of Microorganisms: Impacts of Natural Remedies on Quorum Sensing for Disease Prevention**

Anushka Aiyar, Sophia Kao

The biofilm formation of bacteria, caused by quorum sensing, can lead to severe autoimmune and inflammatory illnesses in the body. Quorum sensing allows bacteria to synchronize group behaviors, making biofilm formation more effective. As such, many strategies to terminate biofilm formation involve targeting quorum sensing. Natural remedies such as garlic, turmeric, ginger, and aloe vera have shown promising results in stopping biofilm formation. This experiment tests out how effective they are at targeting quorum sensing and biofilm formation without high-level scientific processing by growing E. coli alongside blended liquids of the four natural remedies mentioned above. Aloe vera was found to inhibit biofilm formation, but did not inhibit quorum sensing well. Garlic was found to inhibit quorum sensing and biofilm formation effectively. Ginger was effective at inhibiting quorum sensing, but not biofilm formation. Turmeric was not found to inhibit either. Throughout the experiment, garlic seemed to be the most effective natural remedy when used without any further processing, making it a remedy that holds promise in further applications of inhibiting biofilm formation.

The Governor's Academy

**Unlocking Response:Targeting the FTO-Dependent m6A Demethylation to Restore anti-PD-1 Efficacy in NSCLC**

Mingyang Sun

Non-small cell lung cancer (NSCLC) is the most common cancer type globally with high incidence. Immunotherapy targeting the PD-1/PD-L1 axis has shown promise, but many patients fail to respond, underscoring the need to identify novel regulators of immune evasion, particularly given that m6A profiles are implicated in NSCLC carcinogenesis, progression, and treatment resistance.

FTO is a demethylase in m6A epigenetics. Protein expression levels of FTO, ALKBH5, and PD-L1 were assessed by Western Blot in three NSCLC cell lines. FTO knockdown was achieved using siRNA in A549 cells, and its effects on PD-L1 expression were evaluated by Western Blot and immunofluorescence staining. mRNA stability was assessed by actinomycin D chase assay, and tumor cell apoptosis was measured by flow cytometry following co-culture with activated PBMCs.

Our findings revealed that A549 cells exhibited significantly higher basal expression of FTO and ALKBH5. Knockdown of FTO in A549 cells significantly reduced PD-L1 protein expression, as confirmed by both Western Blot and immunofluorescence. Mechanistically, FTO silencing accelerated the decay of PDK1 mRNA, suggesting that FTO regulates gene expression through mRNA stabilization. Functionally, FTO knockdown enhanced apoptosis of A549 cells when co-cultured with activated PBMCs, indicating increased sensitivity to T cell-mediated killing.

Our study demonstrates that FTO positively regulates PD-L1 expression in NSCLC cells by modulating mRNA stability, and that targeting FTO enhances immune-mediated tumor cell apoptosis. These findings provide a foundational basis for exploring FTO as a potential therapeutic target to overcome immune resistance and improve the efficacy of anti-PD-1/PD-L1 immunotherapy in NSCLC.

Groton School

**Keeping Time in Space: How DNA Damage-Induced PAR Signaling Alters Circadian Proteins**

Juwon Lee

Long-duration space environments expose the human body to radiation, microgravity, and disrupted light–dark cycles, conditions known to disrupt circadian rhythms and increase cellular stress. However, the molecular connection between stress-induced DNA damage signaling and circadian rhythm-related (CR) protein regulation remains unclear. In this study, I investigated whether poly(ADP-ribose) (PAR), a signaling molecule produced during DNA damage, alters the activity of PAR-binding E3 ubiquitin ligases that regulate CR proteins.

I hypothesized that certain E3 ligases containing PAR-binding motifs would exhibit altered ubiquitination activity in the presence of PAR and would modify specific circadian rhythm proteins in a PAR-dependent manner. To test this hypothesis, I first identified candidate PAR-binding E3 ligases through computational analysis of a published PAR-binding proteome dataset and motif screening. I then selected E3–CR protein pairs based on motif presence and tissue expression overlap. PAR-dependent ubiquitination activity was evaluated using cellular and in vitro ubiquitination assays under conditions with or without PAR. Ubiquitination was analyzed by Western blot to detect high–molecular-weight poly-ubiquitinated species.

The results showed that different PAR-binding E3 ligases displayed distinct substrate-specific ubiquitination patterns. VPS8 and TRIM9 enhanced poly-ubiquitination of CRY and PER proteins, RNF11 preferentially modified RORγ and NPAS2, and RNF167 and RNF34 strongly ubiquitinated NR1D2. These findings demonstrate that PAR-binding E3 ligases can differentially regulate CR proteins in vitro.

In conclusion, this study provides biochemical evidence linking DNA damage–induced PAR signaling to CR protein turnover. Future research will investigate whether this mechanism operates under physiological stress conditions and in specific brain cell types associated with aging and neurodegeneration.

Lexington High

**Rewriting the Epigenome: The Effect of Stress-Related Psychiatric Disorders on Genome-Wide H3K4me3 Patterns**

Parnika Mysore

Stress is the body's natural response to physical, mental, or emotional pressures. Stress significantly alters the body, but the underlying mechanisms and genes involved are not yet fully understood. This study analyzes genome-wide sequencing data from control and Chronic Social Defeat Stress, or CSDS-exposed samples to identify regions of DNA where the epigenetic marker H3K4me3–commonly associated with gene activation–was bound. These regions are referred to as peaks. Data was converted to BAM files, analyzed using Integrated Genome Viewer and R, and the top ten genes displaying the most statistically significant difference in H3K4me3 enrichment were isolated. This study identified and analyzed 70,437 peaks and discovered that 1,143 of these peaks (1.62% of the total) displayed statistically significant (using $p<0.05$) changes in the experimental mice. The top ten genes coded for vital biological processes such as autophagy, cognitive development, cell signaling, and DNA transcription, highlighting specific ways in which mental health issues may alter normal biological processes in the body. Graphs plotting all changes in peaks indicated that CSDS generally reduces gene activation. Five of the affected genes were undiscovered, suggesting that further scientific research into these regions of the genome is necessary. Pathway enrichment analysis demonstrated an overrepresentation of pathways and diseases pertaining to brain function, cell signaling/hormone secretion, and cell processing. Given that germ cell maturation is controlled by the hormonal secretions of somatic cells, changes to hormonal pathways reveal how stress can impact germ cells. These epigenetic effects that are transferred to gametes can thus potentially be inherited. By identifying specific CSDS-induced changes to gene expression, this study provides clarity on the genome-level mechanisms that drive the large-scale negative effects of mental health issues on the body, paving the way for potential reversal of such chemical alterations and more pinpointed treatments for psychological disorders.

Keywords: DNA modification, DNA methylation, epigenetic regulation, gene expression, psychiatric disorders

**The Effects of Transgenerational Epilepsy on Dementia Pathology in C. elegans**
Parnitha Karapakula

Epilepsy and Alzheimer’s disease are increasingly recognized as comorbid neurological disorders, yet the mechanisms linking them remain unclear. Seizure-induced neuroinflammation may drive epigenetic changes that alter gene expression and can be inherited across generations, potentially increasing dementia risk. This study investigates whether epilepsy produces transgenerational cognitive impairments using Caenorhabditis elegans as a model organism. Seizures were chemically induced in C. elegans using pentylenetetrazole (PTZ). Spatial learning and memory were assessed across three generations using a T-maze chemotaxis assay. Worms were exposed to PTZ either once or repeatedly across generations, and learning performance during training and testing phases was compared to that of unexposed controls. Control worms consistently exhibited robust spatial learning, with significant improvement during training and testing ($p < 0.0001$). PTZ exposure impaired learning in both a dose- and generation-dependent manner. In Generation 2, once-exposed worms showed significantly reduced learning during training ($p = 0.0003$) and testing ($p = 0.0018$), while repeatedly exposed worms displayed stronger deficits. In Generation 3, cumulative exposure further exacerbated learning impairments, with repeatedly exposed worms failing to show significant improvement during testing ($p > 0.05$). Importantly, learning deficits persisted even after PTZ exposure was discontinued, indicating lasting inherited effects. These findings demonstrate that seizure exposure can induce durable, transgenerational impairments in cognitive function. Together, the results suggest that epilepsy may act as a transgenerational risk factor for dementia, potentially mediated by heritable epigenetic mechanisms. Future studies will examine DNA methylation and amyloid-beta accumulation to identify targets for preventative interventions.
Keywords: epilepsy, Alzheimer’s disease, dementia, epigenetics, transgenerational inheritance, C. elegans

**Parental Pharmacological Modulation of Serotonergic Signaling in C. elegans to Analyze Hereditary Suicide.**

Sahasra Charkam

Familial aggregation studies indicate that genetic and epigenetic factors contribute to inherited vulnerability to suicide and major depressive disorder (MDD). The serotonin transporter gene (SLC6A4) regulates synaptic serotonin levels and influences neural circuits involved in emotional regulation. Caenorhabditis elegans provides a genetically tractable model for studying conserved serotonin-dependent behaviors, exhibiting similar behavioral phenotypes to those of humans. This study tested whether pharmacological disruption of serotonergic signaling in adult parental worms induces transgenerational behavioral alterations in F1 offspring. Because serotonin dysregulation is associated with MDD and suicide risk in humans, I hypothesized that reducing serotonin signaling in parental worms would produce a depressive-like phenotype in F1 offspring. In contrast, enhancement with fluoxetine would mitigate these effects. Parental (P0) worms were exposed to 6.25 μM reserpine for 24 hours and subsequently either maintained in reserpine or transferred to 6.25 μM fluoxetine for an additional 24 hours. After 48 hours, reserpine-treated P0 worms exhibited significantly reduced pharyngeal pumping rates (~85 pumps/min) compared to wild-type controls (~250 pumps/min). While most F1 groups showed no significant differences, offspring of the 48-hour reserpine group displayed persistent reductions in pumping (~100 pumps/min; Student’s t-test, $p < 0.001$). These findings suggest that parental serotonergic disruption can induce transgenerational behavioral effects, providing a model to investigate biological mechanisms relevant to inherited vulnerability to affective mood disorders.

**Neuroprotective Effects of Insulin Signaling Modulation in an Alzheimer’s Model**

Atharv Joshi

Alzheimer's disease (AD) is a progressive neurodegenerative disorder characterized by the accumulation of amyloid-β (Aβ) and tau proteins, leading to cognitive and motor decline. More than 6 million Americans have AD, though there is no cure or effective treatment. Currently, many underlying disease mechanisms remain unresolved. Central to ongoing debate is the "insulin paradox": while reduced insulin signaling protects model organisms from Aβ toxicity (Huang et al., 2019), mounting clinical evidence links insulin resistance to accelerated AD pathology and cognitive decline (Chen et al., 2023; Livingston et al., 2024). To address this discrepancy, this study uses Drosophila melanogaster to examine how altering insulin signaling affects neurodegenerative outcomes in a TBI-induced AD-like model. Flies were subjected to controlled mechanical injury using an improved HIT (high-impact-trauma), incorporating a second spring for consistent impact localization, reduced oscillation, and minimized human error. Neurodegeneration was quantified using negative geotaxis and olfactory T-maze assays. Flies with enhanced insulin signaling (InR overexpression) showed a 39.6% lower decline in climbing ability and a 46.8% lower impairment in learning performance compared to wildtype TBI controls. Conversely, flies with reduced insulin signaling (Chico knockdown) showed a 20.8% greater decline in climbing ability and a 9.0% greater impairment in learning performance versus wildtype TBI. These findings resolve the insulin paradox in a TBI context. Insulin signaling is neuroprotective, and its suppression accelerates neurodegeneration. Therapeutic strategies that preserve or restore insulin signaling in the brain may offer promising avenues for mitigating neurodegeneration in AD and brain injury-related conditions.

Littleton High School

**Effect of Resveratrol and Turmeric on Tumor Growth in Hydra littoralis**

Samhita Gowda

Acton-Boxborough Regional High

**Ameliorating Effects of Hesperidin and Curcumin on Nrf2-Keap1 Parkinson’s Mechanisms in Drosophila melanogaster**

Deepika Bhardwaj, Yoyo Wu, Nandita Ganesh

To clarify hesperidin’s and curcumin’s potential as natural antioxidants to improve PD prognosis, we investigated the effects of hesperidin and curcumin treatment on LRRK2-mutant Drosophila melanogaster to elucidate oxidative stress pathways, autophagic mechanisms, and potential synergism of the two antioxidants. D. melanogaster behavior, such as climbing ability and locomotor activity, was monitored through video camera footage and computational analysis of whether behavioral prognosis was improved following treatment with hesperidin, curcumin, and control treatments. Our results suggested that hesperidin and curcumin alleviated oxidative stress, including H2O2-induced stress, in both Canton-S wild-type strains and LRRK2-mutant D. melanogaster models of PD. The locomotor activity of D. melanogaster improved across both strains when treated with hesperidin, curcumin, or tandem hesperidin/curcumin treatments, further supporting their proposed antioxidant properties and aligning with prior literature. Hesperidin’s autophagic upregulation and curcumin’s activation of Nrf2 show significant potential in alleviating the motor defects caused by PD dopaminergic neurodegeneration, and may even prove meaningful to long-term autophagy and antioxidant control, and thus bring health benefits to everyone. Overall, by examining the potential hidden benefits of hesperidin and curcumin as affordable and effective treatments for neurological disorders, our study aims to promote healthier lifestyles and mitigate PD risk through natural solutions.

**The Impact of Increased Salt Concentrations on Fungi-Bacteria Ratios in Local Topsoils, and an Exploration Into Effects on Overall Soil Health**

Quinlan Kelly, Helena Brain

This project investigated how salt exposure may affect different soil types (eg. with high concentrations of sand, clay, or loam) by examining microbial communities. Total microbial biomass, fungi to bacteria ratio (F:B), pH, and soil respiration (measured via $CO_2$ output) were recorded over the course of this investigation. The purpose of this project was to determine the extent to which varying levels of salt exposure may impact the balance and quantity of microorganisms found in the soil, and if these changes varied when comparing different soil types. It was hypothesized that if local topsoil samples are treated with 0%, 1%, and 3% NaCl solutions, the more saline the solution is, the greater the community disruption and decrease in biomass. It is also predicted that bacteria populations will have a larger percent decrease than fungi populations. Additionally, between soil type groups that received identical concentrations of the saline solution, there will be statistically significant differences between the change in F:B between each soil type (sand, loam, clay). To test this, soil samples were taken from three sites that each had been previously identified as having soils with high concentrations of loam, clay, and sand. After multiple initial tests, samples were exposed to salt solutions of varying concentrations (0%, 1%, 3%) then retested for microbial biomass and F:B at the 10 day and 20 day marks. Following statistical analysis, salt concentration appears to have significant effects on the composition of the microbial community in these soils, but not on the total overall quantity of microbial biomass. These findings may help to inform road salting plans and allow for the more intentional selection of roadside soil following new construction.

Key Terms: soil, microbial communities, fungi bacteria ratio, road salt, clay, sand, loam

North Reading High

**The Effects of Chlorine on the Structure and Integrity of Different Types of Human Hair**

Adelyn Kelly

Chlorine plays a critical role in keeping pools clean and safe for all swimmers. However, it threatens the structure and integrity of proteins that enter the water including keratin, the protein that makes up 90% of human hair. This study aimed to determine how different concentrations of chlorine, representing a normally chlorinated pool and an overly chlorinated pool, affect hair. The effect on hair was measured by comparing the force required to break a strand of hair, the weight of a bundle of hair, and the visual appearance of hair which can be observed under a microscope. A controlled experiment was conducted, using nine small bundles of hair which were obtained from a hairdresser. These bundles were manipulated by each being assigned to two conditions that were unique from every other bundle. These conditions included being exposed to either 0ppm, 3ppm, or 8ppm of chlorine, as well as being treated with either water, conditioner, or nothing before exposure. The resulting structure and integrity was measured using microscopy, a tensile strength test, and a scale to measure changes in mass. A two way ANOVA will be used for statistical analysis with the explanatory values being the level of chlorine and the treatment added to the hair before exposure, while the response will be the resulting strength of the hair.
Key terms: Chlorine, human hair, structure, integrity, water, conditioner, microscopy, tensile strength test, changes in mass, two way ANOVA

**Delivery of Fluorescent Markers to MDCK and BHK Cells via Iron-Based Nanoparticles**

Alexandra Hilley, David  Onitiri

Nanoparticles have been widely investigated as drug delivery systems; however, their clinical implementation has been limited by challenges in scalable production. In this study, we evaluated the novel iron-based nanoparticle, ETAERION-Carrier, designed for scalability, for its ability to facilitate intracellular transport. In vitro experiments were conducted using Madin-Darby Canine Kidney (MDCK) and Baby Hamster Kidney (BHK) cells as model systems, which allowed for the assessment of how the nanoparticles' effectiveness differs between cell lines, and AQuora® Fluorescein Reporters as a visual representation of a product being transported. Cellular uptake, measured by fluorescence intensity inside cells, was compared across untreated controls, experiments treated with unassociated reporters, and experiments treated with nanoparticle-associated reporters, which allowed for the assessment of how the nanoparticles affect the efficiency of the reporters' intracellular transport. Experiments were incubated for different lengths of time, which allowed for the assessment of how the nanoparticles' effectiveness differs by incubation time. ETAERION-Carriers and AQuora® Fluorescein Reporters were provided by Paretor™.

Worcester Academy

**Different Herbal Extract's Antibiotic Effects on Bacteria**

Sharvi Sharma

Multi-drug-resistant bacteria are a growing global health crisis, with many infections increasingly resistant to antibiotics. Herbal extracts, such as thyme and clove, have shown potential antimicrobial activity, but few studies have examined their combined effects. In this study, thyme and clove were tested as 10% methanol extracts and essential oils against Pseudomonas fluorescens using disk diffusion, with water, methanol, and four antibiotics as controls. A second experiment evaluated six 50:50 combinations to assess synergistic effects. Clove methanol and clove essential oil outperformed the average antibiotic activity in the plain extract groups, while thyme extracts were less effective. Synergistic combinations, particularly thyme essential oil plus clove methanol, showed higher inhibition than individual treatments and most antibiotics, indicating synergistic effects. Overall, most extracts and combinations matched or exceeded antibiotic performance, highlighting their potential as complementary or alternative antimicrobial agents for combating antibiotic-resistant bacteria.

Concord Academy

**SRPK1 Modulates Survival Signaling Pathways in Parkinson's Disease: Evidence from Integrative Transcriptomics and Cellular Validation**

Zijia Li

Parkinson's disease (PD) is a progressive neurodegenerative disorder characterized by dopaminergic neuron loss and dysregulated survival signaling pathways. In this study, we performed an integrative bioinformatic analysis of PBMC transcriptomic data from sporadic PD patients (GSE75249), identifying 4,150 differentially expressed genes (DEGs), with a predominant pattern of down-regulation. Functional enrichment analyses revealed significant involvement of the PI3K-AKT, MAPK/ERK, mTOR, and other neurodegeneration-related pathways. Protein-protein interaction (PPI) network analysis identified SRPK1 as one of the highly connected, down-regulated hub genes in PD samples. However, the function of SRPK1 has not been fully reported in PD. Experimental validation in the MPP+-induced SH-SY5Y cellular model confirmed reduced SRPK1 expression under MPP+ neurotoxic stress. Notably, overexpression of SRPK1 in the PD cell model improved cell viability and significantly attenuated MPP+-induced apoptosis and intracellular reactive oxygen species (ROS) accumulation. Furthermore, an inverse correlation was observed between SRPK1 and SNCA (the gene encoding α-synuclein), as SRPK1 overexpression decreased SNCA mRNA levels, whereas pharmacological inhibition of SRPK1 with SRPIN340 increased them. These findings suggest a neuroprotective role for SRPK1 in neuronal stress adaptation and cell survival. Collectively, this study identifies SRPK1 as a novel PD-associated hub gene and potential blood-based biomarker and therapeutic target, providing new insight into kinase-regulated translational and survival mechanisms in PD.

Newton South High

**Comparative Effectiveness of Traditional and Modern Antimicrobial Agents Against Escherichia coli**

Alexander Peresypkin

For my project, I plan to investigate how different factors, including environmental stressors and common household antimicrobial agents, affect the growth of E. coli. I chose E. coli because it is a common, laboratory model organism, making it safe and representative for studying bacterial responses to stress. For example, I will test the impact of UV light exposure on the bacterial viability, as well as comparing the inhibitory effects of household cleaning chemicals on the E.coli. I will use the Zone of Inhibition method to collect measurable data on how effective each treatment is at preventing E. coli growth. The goal is to compare how different factors, from UV light to everyday cleaning products, affect E.coli, with the findings providing insight into effective sanitation practices crucial for public health.

Worcester Technical High

**Impacts of Efflux Pumps Inhibitors on Antibiotic Sensitivity**

Neslon Tetteh, Kevin Arias Rivera, Aryan Sharma

Antibiotic resistance has become one of the most pressing global health challenges, driven largely by the overuse and misuse of antibiotics. Bacteria that were once easily treated now evade therapy, raising the alarming possibility of returning to a pre-antibiotic era where minor infections could be fatal. A central mechanism of resistance is the activity of efflux pumps, which actively expel antibiotics from bacterial cells, lowering intracellular drug concentrations and contributing to multidrug resistance.

Efflux pump inhibitors (EPIs) offer a promising strategy to restore antibiotic efficacy by blocking these pumps and preventing drug expulsion. This project aims to evaluate the impact of EPIs on antibiotic susceptibility in Escherichia coli. The hypothesis is that combining EPIs with antibiotics will enhance bacterial sensitivity compared to antibiotics alone.

Two experimental approaches will be employed: a broth microdilution assay to measure bacterial growth via optical density (OD600), and a disk diffusion assay to assess susceptibility through zones of inhibition. Enhanced antibiotic activity in the presence of EPIs—indicated by larger inhibition zones and reduced growth—would demonstrate that efflux pump inhibition increases antibiotic effectiveness.

**Are Our Bacteria Passive Smokers**

Ugonna Njoku

Background: While the harmful effects of smoking on human health are well-known, its impact on the "good" bacteria in our bodies—specifically the vaginal microbiome—is less understood. This study investigated how cotinine (a chemical produced when the body breaks down nicotine) affects the growth of Lactobacillus, a group of beneficial bacteria essential for maintaining reproductive health.

Methods: We exposed Lactobacillus cultures to various concentrations of cotinine and a control solution (placebo) under conditions that mimic the human body. The bacteria were grown in an anaerobic chamber, and their growth was measured by counting Colony Forming Units (CFU) across three separate experiments.

Results: The data consistently showed that bacteria exposed to cotinine grew less effectively than those in the control group. Across all tested concentrations, there was a measurable reduction in bacterial recovery, suggesting that even the chemical byproducts of nicotine can hinder the survival of these protective microbes.

Conclusion: These preliminary findings suggest that smoking may negatively impact vaginal health by suppressing beneficial bacteria. This could potentially leave the body more vulnerable to infections by disrupting the natural microbial balance.

Boston Latin School

**Comparative Effects of Antioxidants and Antioxidant Enhancing Compounds on Heat Induced Oxidative Stress Pigmentation Changes in Danio Rerio Embryos**

Jared Acevedo, Chelsea Bateman

Zebrafish (Danio rerio) have been advanced models for biomedical research since the 1960s. Their use throughout the decades is due to their genetic similarities with humans (70% of genes shared), rapid development, and high optical transmittance. Prolonged exposure to oxidative stress can lead to the development of melanoma and other diseases in both humans and zebrafish through increased ROS production. Antioxidants like Vitamin C and glutathione, which is produced by the compounds NAC and manganese sulfate, can reduce the number of free radicals in the body by completing their valence electrons. Our project sought to determine whether Vitamin C, NAC, and manganese sulfate lower thermally induced oxidative stress and therefore reduce hyperpigmentation caused by increased ROS in the body. We counted the death rates, hatch rates, and deformities of 120 zebrafish embryos from 1-5 dpf and later used a pigmentation scale and double blind ranking system to assess the pigmentation on 460 zebrafish embryos 1-5 dpf in order to assess the effects of NAC, Vitamin C, and manganese sulfate on oxidative stress mitigation. We induced oxidative stress with a 30 degree celsius incubator, while our control groups were kept in a 28.5 degree incubator, the standard for raising healthy zebrafish. We performed Kruskal-Wallis test to determine a statistically significant increase in pigmentation scores due to thermally induced stress, followed by a Dunn's comparison to observe a statistically significant ability for all three compounds to mitigate the increase in pigment caused by this oxidative stress, thus proving our experiment successful.

Boston Latin School

**Identifying a Receptor for a Newly Discovered Gene Therapy Vector**

Yifan Ding

Gene therapy uses harmless viruses called adeno-associated viruses (AAVs) to deliver healthy genes into cells to treat disease. However, one major challenge is delivering genes efficiently to the brain. The engineered AAV variant AAV.CPP.16 can enter brain cells in both mice and primates, but the reason for its strong brain-targeting ability was unknown.

In this project, I investigated which cellular receptor allows AAV.CPP.16 to enter brain cells. Based on similarities to other AAV variants, I hypothesized that it might bind to a protein in the LY6/uPAR family. Using cell culture experiments, I tested candidate receptors one by one. I found that a protein called LYPD6 significantly increases AAV.CPP.16 binding and gene delivery. When LYPD6 was removed from cells, viral transduction was reduced, confirming its importance. In situ hybridization data further showed that LYPD6 is expressed in mouse, primate, and human brain tissue.

These findings identify LYPD6 as a receptor for AAV.CPP.16 and help explain its cross-species brain tropism. Understanding this interaction enables more rational design of improved gene therapy vectors and may support future treatments for severe neurological disorders.

Grafton High School

**Testing and Developing a Reliable Enzyme Encapsulation System for β-Galactosidase**

Lauren Piel, Navadha Padliya, Anushka Singh

This project investigated whether a double-layer encapsulation system could improve the stability and effectiveness of β-galactosidase (lactase) during digestion. Because lactase denatures in highly acidic environments, the research question asked whether a multilayer bead design could better protect the enzyme in simulated gastric conditions while preserving activity in simulated intestinal fluid. It was hypothesized that a double-layer system consisting of an alginate inner matrix coated with gelatin would provide greater protection and more consistent enzyme release than single-layer systems or a commercial supplement. Six treatment groups were tested: single-layer alginate beads, pectin beads, gelatin capsules, double-layer alginate plus gelatin beads, a store-bought Lactaid tablet, and a fresh enzyme baseline control. Samples were exposed to simulated gastric fluid (pH 2) for 45 minutes, then transferred to simulated intestinal fluid (pH 7). Lactose substrate was added, and glucose production was measured using test strips to quantify enzyme activity. Three trials were conducted per group. The fresh enzyme control produced the highest glucose levels. None of the encapsulated treatments, including Lactaid, reached this maximum activity, as expected, indicating that while encapsulation improves acid stability, it may slightly reduce peak enzyme availability due to diffusion limits or incomplete release. However, the double-layer beads demonstrated the most consistent and reliable glucose production and outperformed the commercial supplement based on our trials. These results suggest that multilayer encapsulation improves acid protection but may slightly limit peak enzyme release. Future research could optimize bead size, surface area-to-volume ratio, and enzyme loading capacity to further enhance performance.

**Investigating The Neuroprotective Effects of C.Asiatica on Lithium-Deficient Saccharomyces cerevisiae Cells as a Model for Progressive Neurodegenerative Diseases**

Mahathe Logesh

Alzheimer's disease (AD) is a progressive, neurodegenerative disorder, also known as the common form of dementia, characterized by memory loss, cognitive decline, and behavioral changes. Globally, the number of Alzheimer’s cases is projected to double from 6.9 million in 2020 to around 14 million in 2060 (CDC). While Alzheimer’s is diagnosed after significant brain damage, much evidence suggests that early cellular and molecular change occur long before serious neurological impairment. AD is associated with the accumulation of misfolded proteins, mitochondrial dysfunction, oxidative stress, and disrupted cellular signaling. Lithium plays a key role as it is a naturally occurring element in the brain, regulating enzymes such as GSK-3 (glycogen synthase kinase 3), an enzyme related to phosphorylation. Numerous studies have shown that a low level of lithium may be associated with greater risk for cognitive decline. However, the mechanism of lithium deficiency and cellular effects, particularly in the initial phases before neurodegeneration, is yet to be fully understood. Despite GSK-3 regulation, lithium impacts several intracellular processes interconnected with early Alzheimer’s pathology. In addition, lithium has been shown to stimulate autophagy, a cellular recycling process responsible for clearing misfolded or aggregated proteins such as abnormal tau and amyloid beta. Impaired autophagy is considered an early contributor to harmful protein buildup in neurodegenerative disorders. Mitochondrial instability and oxidative stress are also disrupted prior to neuronal damage, contributing to impaired energy production, reduced synaptic activity, and altered metabolic balance. Disruptions in key cellular signaling pathways may further affect protein synthesis and stress response mechanisms. Due to the complexity of these early molecular changes, they are difficult to study directly in human patients. Therefore model organisms such as Saccharomyces cerevisiae can be utilized to investigate conserved cellular pathways including stress response, mitochondrial function, and protein quality control. Centella asiatica, a medicinal herb known for its antioxidant and neuroprotective properties has been shown to support mitochondrial function and reduce oxidative stress, To further enhance the therapeutic potential, this study incorporates a green nanotechnology approach by synthesizing silver nanoparticles (AgNPs) using Centella asiatica extract at varying concentrations. These nanoparticles were evaluated alongside lithium and herbal extract treatments, both individually and in combination, using a yeast model to assess cell viability and protection against stress-induced damage.In addition, a bioinformatics approach using network pharmacology and molecular docking was employed to identify the phytochemical targets and the associated neurodegenerative pathways. Target prediction, protein to protein interaction network construction, and pathway enrichment analysis were conducted to determine key genes and mechanisms involved. Researching the combined effects of lithium, Centella asiatica, and its nanoparticle derivatives may clarify the role of lithium deficiency in early cellular dysfunction and provide insight into potential neuroprotective strategies for preventing Alzheimer's disease before irreversible neurodegeneration occurs.

**Topical Soil Transplantation: A Novel PGPM Fertilization Strategy for V. radiata**

Valerie Lindh

PGPMs (plant growth promoting microorganisms) are essential to the growth of plants, especially legumes such as V. radiata. Current efforts in the agriscience sector to create PGPM fertilizer are limited by factors of transportation and PGPM-crop specificity. Topical Soil Transplantation was developed with inspiration from fecal transplants, in which microorganism-harboring organic material is applied as a supplementive inoculant. Rhizospheral soil of an unsterilized V. radiata crop was topically transplanted to the surface soil of an initially sterilized test group of V. radiata plants, while a control V. radiata crop recieved a transplant of sterilized soil of an identical quantity. Statistical analysis found that the test group showed higher magnitudes of growth within the metric of mean height, mean root nodule amount, median root depth, and lesser growth rate decrease after inoculation, suggesting Topical Soil Transplantation is an effective method of PGPM fertilization in V. radiata.

**Say Goodbye to Pests and Pesticides: Exploring the Effects of Potassium Soil Levels on Druse Idioblasts Containing Calcium Oxalate Crystals in Spinacia Oleracea**

Khadeja Mukassabi

Pests are a serious problem as they cause drastic negative impacts on global food production. The current solution, using pesticides, causes even bigger issues: having detrimental impacts on the environment, human health, and the economy. Druse crystal idioblasts are specialized cells that create calcium oxalate crystals, which have been shown to deter pests away from plants. This study sought to answer the question of how changes in potassium concentration increase the formation of druse crystal idioblasts in spinach plants, supplying farmers with a novel pesticide-free solution for pest defense. Spinach plants were grown in a greenhouse and watered via a modified hydroponic system. Five potassium treatments were tested (0, 60, 120, 180, and 300 mg/L: 0 mg/L being the control group). After 43 days, spinach leaves were selected for idioblast density analysis. ANOVA test results indicated that potassium concentration impacted druse crystal idioblast density. Tukey HSD test results showed druse crystal idioblast density remains consistent among lower potassium levels (0-60 mg/L), plummets at 120 mg/L, peaks at 180 mg/L, and slightly decreases at 300 mg/L. Growth charts indicated no significant change in growth across treatment groups. The results show 180 mg/L is the optimal potassium level for maximum druse crystal idioblast density in spinach plants. Spinach farmers who want to minimize crop loss from pests, without relying on pesticides, should ensure soil potassium level is 180 ppm. Further research can replicate this study on high-yielding crops.

Keywords: Potassium, Druse crystal idioblast, Plant defense, Spinach

Westfield High School

**Acheta domesticus Consumption Rates as a Function of Varying Electromagnetic Wavelengths**

Kaitlynn Goulette

Artificial light pollution is an increasing environmental concern with significant effects on insect behavior. This project studied how exposure to different visible light wavelengths influences food consumption in Acheta domesticus (house crickets). Crickets were continuously exposed to red, blue, white, or no artificial light. Consumption rates were calculated as the percentage of food consumed by measuring standardized food portions before and after feeding periods.

Crickets exposed to blue light demonstrated the highest mean consumption rate (68.39% ± 5.32%), followed by red light (66.92% ± 7.60%) and white light (64.03% ± 7.89%). The no-light control group showed the lowest average consumption (63.29%) and the greatest variability (± 8.53%). These findings contradict the original hypothesis that crickets in natural, unlit conditions would exhibit the highest feeding rates.

The results suggest that exposure to specific wavelengths of artificial light, particularly blue light, can increase feeding behavior in Acheta domesticus, potentially due to circadian disruption or increased activity rather than improved environmental conditions. This study highlights the importance of wavelength-specific effects when evaluating the ecological impacts of artificial lighting.

**How Plant Spacing Affects Growth Rate**

Paige Mello

This science fair experiment investigated how plant-to-plant contact and plant signaling affects the growth rate of basil plants grown in a controlled aeroponic system. The study aimed to test the hypothesis that increasing the distance between plants would decrease their growth rate due to reduced plant communication and interaction. Over a four-week trial, the results indicated that isolated plants grew significantly taller (average 7.493 cm) and achieved a higher biomass (average 20.17 g) compared to competitive plants, which reached an average height of only 3.81 cm and a biomass of 18.44 g. Interestingly, while the competitive plants were smaller in overall size, they produced a higher number of leaves, increasing from 10 to 18 compared to the isolated plants' increase from 7 to 12. These findings suggest that crowded environments may trigger a stress response involving the release of allelochemicals like benzoic acid, which induces ethylene production to inhibit the growth of neighboring competitors. Therefore, while isolated plants focus on overall height and mass, competitive plants may prioritize leaf production as a response to environmental stress.

North Quincy High

**Chemical Fertilizers and the UV-B Tolerance of Plant Cells**

Vivien Huang

Hydroponic Vigna radiata plants receiving 5 hours of intense UV-B light rays each day were grown with different fertilizers to explore the effect of intense radiation on plant cells. As well as the purpose and use of different chemical fertilizers, such as urea, potassium chloride, and superphosphate. When hydroponic Vigna Radiata plants were grown under 5 hours of intense light rays and received one of the three chemical fertilizers, urea, superphosphate, or potassium chloride, then the plant receiving potassium chloride grew 5 cm taller than the average height (cm) of all plants and was ~11% less likely to develop yellow pigments in its leaves. Vigna radiata plants grown in distilled water were placed under a UV-B lamp fixture; each plant received 5 hours of sunlight for 28 days. Every week, the corresponding plant will received 5 g of its chemical fertilizer diluted in 30 ml of distilled water. The height of the plant was measured every day, and the pigment of its uppermost and lowermost leaves was also recorded every day. The plants grown with potassium chloride as their fertilizer showed the highest increase in overall growth (6.03 cm), whereas the plants grown with urea showed the lowest increase in overall growth (4.15 cm). However, when the pigment was compared, the plants grown with urea were observed to have greener pigment compared to those grown with distilled water. Identifying which chemical fertilizer promoted plant growth best under extreme radiation allowed for healthy plant growth when only artificial light was present.

Weston High

**The Secret Language of Mycelium**

Johan Coisman

It is well known that mycelial networks generate electrical impulses in response to environmental stimuli. These signals disseminate information within the networks, but it is not known whether they are limited to simple responses or are a more advanced form of communication. This project investigates whether this electrical activity in mycelial networks constitutes a proto-language.

Reishi mushroom (Ganoderma lucidum) mycelium blocks were stimulated with three types of environmental inputs: mechanical pressure, temperature change, and exposure to an acidic solution. Electrical activity was recorded using an OpenBCI Cyton biosensing board and electrodes placed at three distances from the stimulus source (2 cm, 6 cm, and 10 cm). Each trial included a two-minute baseline period followed by stimulus application and 5 1/2 minutes of signal recording. Fourteen combinations of stimuli plus a control were tested (each with six replicates) resulting in 90 trials.

Several metrics were drawn from the electrical recordings including baseline voltage, peak voltage change, signal latency, spike frequency, and electrode distance. The data were analyzed with statistical methods including simple ANOVA, linear regression, linear discriminant analysis, and factorial ANOVA.

The results showed that the electrical impulses propagated through the mycelial network and decreased with distance which is consistent with propagation. Different types of stimuli were distinguishable from one another and combinations of stimuli interacted in ways that were not exclusively additive. The results were linguistically consistent with a proto-language although more research needs to be done to further validate this conclusion.

Sturgis East Charter Public School

**Chlorella vulgaris in Conjunction with Nitrogen Fixing Bacteria as an Aid to Plant Health and Synthetic Fertilizer Replacement**

Emily Ward

Agriculture is a significant contributor to excess atmospheric carbon dioxide, and while crops require essential nutrients in order to thrive, synthetic fertilizer is unsustainable in terms of greenhouse gas emissions as well as negative environmental impacts on cropland when it is applied. The project was designed to evaluate a new farming strategy which consists of the application of Chlorella vulgaris, a species of freshwater microalgae, to replace standard synthetic fertilizer, while improving soil and plant health. C. vulgaris increased Alfalfa (Medicago sativa subsp. sativa) and China rose radish (Raphanus sativus) growth over control conditions, which resulted in greater shoot height and leaf width. Nitrogen fixing bacteria, Azotobacter vinelandii and Azospirillum brasilense, were applied alongside C. vulgaris to improve the plant's ability to take in nutrients from the system, which increased nitrogen availability and increased root length and chlorophyll content over C. vulgaris application alone. This project resulted in the demonstration that it is viable to replace synthetic fertilizer with sustainably produced microalgae as a nutrient source for crops. This approach leads to a net reduction in greenhouse emissions from both the natural atmospheric decrease in carbon dioxide from production of C. vulgaris due to photosynthesis, and a lack of emissions from synthetic fertilizer production which has been removed from the production strategy. Adoption of the demonstrated crop production solution will benefit the planet by reducing the emission of pollutants which cause climate change, while also creating the sustainable conditions for improved soil health and enhanced crop production.

Keywords: Chlorella vulgaris, climate change, carbon dioxide, nitrogen fixing bacteria, radish, alfalfa, hydroponics, fertilizer replacement, sustainable agriculture, microalgae

Hopkinton High

**Noninvasive Inference of Presymptomatic Plant Stress from Latent Electrophysiological Dynamics via Action Potential-Based Hybrid LR-CNN Fusion Model**

Jacob Wu, Rudra Pachori, Yulhee Kwon

Early detection of plant stress is critical for agriculture, but current methods rely on visible symptoms that appear only after physiological damage has occurred. Stress alters cellular dynamics, so electrophysiological signals, which directly reflect these changes, present a promising, underexplored approach for presymptomatic detection. Thus, we hypothesized that abiotic stress induces measurable alterations in plant action potentials (APs), enabling stress identification before visible symptoms. 320 plants (80 pothos, 80 tomato, 80 sorghum, 80 wheat) were randomly assigned to control, salinity stress, nutrient deficiency, and osmotic stress groups ($n = 80$ each), and standardized stimuli were applied. APs were recorded by a Plant SpikerBox, and physiologically-derived waveform parameters were extracted. To evaluate the informational content of signal representations, three analytical models were applied: (1) logistic regression (LR) on parameters, (2) a convolutional neural network (CNN) on waveforms, and (3) a hybrid LR-CNN combining both feature types. Models were assessed via k-fold ($k = 5$) cross-validations, with fold-wise ROC-AUC compared using a Wilcoxon signed-rank test. The LR-CNN outperformed individual models ($p < 0.05$ vs both; ROC-AUC = 0.9872, F1 = 0.9660) and detected stress on average $4.6 \pm 1.4$ days before visible symptoms. An omics analysis revealed differential expression of genes and miRNAs related to ion channels and calcium transport, supporting the mechanistic basis of waveform alterations. This project presents the feasibility of presymptomatic plant stress detection using electrophysiological biomarkers, which enables timely agronomic intervention, improved crop resilience, and enhanced food security.

Keywords: plant electrophysiology, action potentials, machine learning, abiotic stress

Bancroft School

**Effects of the Combined T-DNA Insertion Mutant of TMM Gene and EPF2 Gene in Arabidopsis Thaliana on Drought Resistance**

Vivian McManus, Amalia Price

Drought is the main environmental stressor and is considered one of the most critical threats to food security in the future. Stomata, small pores on plant leaves, regulate water loss and gas exchange, and their development and spacing is controlled by genes including Too Many Mouths (TMM) and Epidermal Patterning Factor 2 (EPF2). This study investigated whether a combined T-DNA insertion mutant of the TMM and EPF2 genes in Arabidopsis Thaliana would improve plant survival under drought-like conditions compared to single gene mutants and wild-type controls. T-DNA insertion mutant lines for each gene were obtained and crossbred to produce a double mutant. We have two different environments: the control environment and the drought heat environment. Additionally, within each environment, there are two watering types: drought and control watering types. Growth was measured through plant height (mm), leaf length (mm), color (1-5 scale), and flowering rate. PCR and gel electrophoresis were used to confirm the presence of the single and double gene insertions in the experimental plants. Data will be be analyzed for statistical significance.

**Using Drosophila to Test Vitamin B's effect on SLE**

Yuchen Wang

**The Effect of the Gut Microbiome on Mood-Related Behaviors in Drosophila**

Hei Tung Ng

Lincoln-Sudbury Regional High

**From Detection to Prescription: A Frugal, On-Device Multimodal AI System for Real-Time Plant Disease Diagnosis and Management**

Fariba Khan

Tomato plants suffer from multiple visually similar diseases, making early detection difficult for farmers—especially in resource☐limited regions. I designed a frugal, multimodal AI system that runs entirely on☐device (Raspberry Pi or smartphone) and uses three inputs—image, text, and environmental sensor data—to diagnose plant diseases.
My pipeline includes:
Custom multimodal dataset creation,
Leaf detection using YOLOv4,
Disease classification using fused CNN + BiLSTM + MLP networks, and
Deployment in a cross☐platform mobile and Raspberry Pi app ("Plant Doctor").
The final fused model (ResNet50 + BiLSTM + MLP) achieved the highest accuracy across 3☐fold cross validation. The system provides real☐time diagnosis and prescriptive recommendations, demonstrating that low☐cost multimodal AI can support small☐scale agriculture.

**Exploring Sustainable Agriculture through Soil Carbon Sequestration**

Noah Balon

**The Effect of Algae Preventatives on the Propagation of Algae**

Kiley Kruger

Algal blooms on average can wipe out millions of aquatic organisms annually. This project will test the effectiveness of copper-sulfate, barley straw extract, and aquatic dies in reducing algae propagation. This can be used to identify the optimal solution to inhibit growth to decrease harmful algal blooms. It was hypothesized that if preventative measures are used, algal propagation will be reduced. If copper sulfate is used, then the most algal propagation will be reduced. Significant research has been performed to identify methods of prevention of algae blooms and this project aims to further that research by comparing the several methods. This experiment tested Chlorella, Scenedesmus, Selenestrum, Ulothrix, and Volvox under each preventative to discover the optimal treatment. During experimentation the initial and final turbidity for each sample was recorded using a turbidity sensor. The project was conducted for 10 days. The data indicated that aquatic dye was the most effective treatment. The aquatic dye was given the proper amount of time and it is capable of preventing all types of algae, explaining why it was the only treatment that successfully inhibited algae, whereas the copper sulfate was not capable in inhibiting the growth of Selenestrum, Ulothrix, and Volvox and barley straw extract was not given enough time to activate. Further recommendations for research include testing many variations of preventatives, including Quats, Sodium Carbonate Peroxyhydrate, sodium bromide, barley straw, and beneficial microbes, as well as testing many species of algae, including cyanobacteria, dinoflagellates, and diatoms. There is not one solution for algae treatments, rather further testing for proper application within location, algae species, and impact on ecosystems.

Wachusett Regional High

**The Effect of a Natural and Artificial Yellow Dye on Drosophila Populations and Preference**

Kelly Mills

There have been calls for replacing synthetic food dyes, including Yellow 5 (tartrazine), with natural dyes, including beta-carotene extract from the microalgae Dunaliella salina. The project used Drosophila melanogaster to test for offspring population size and dye preference.

In a population assay, a generation of D. melanogaster were laid and raised in a dye-containing food source, with appropriate controls and two dye concentration levels. Once the flies matured, the populations were sorted by sex and counted. It was hypothesized that flies exposed to tartrazine would decrease in population, and those exposed to D. salina beta-carotene would increase or remain the same. This was partially supported as the flies exposed to tartrazine had a decrease in offspring population. However, the same was true for flies exposed to beta-carotene, raising concern that the natural dye is no safer.

In a preference assay, it was hypothesized that flies pre-exposed to a specific dye would prefer that dye over the other options in their food. However, in general the flies had an equal tendency to avoid or choose the dyed food regardless of pre-exposure.

In the future, I could use other sources of beta-carotene or compare other synthetic dyes to their natural counterparts. I would also expand the dye concentration range and include the pattern of effect on future populations. The impact of the experiment is to advocate for caution as the food industry replaces harmful synthetic dyes with allegedly safer natural alternatives.

Keywords: Drosophila melanogaster, food dyes, toxicity

**The Effect of Activated Carbon on the Heart Rate and Daphnia magna Affected by Glyphosate and 2, 4-D**

Miles Wilander

Glyphosate and 2, 4-D are some of the most common herbicides throughout the world. Through runoff, they often end up in water systems, which is detrimental to the organisms living there. This study tests the effects of activated carbon on Daphnia magna affected by these contaminants. Activated carbon has been shown to absorb these herbicides, and could reduce their effects and thus be used as a filtering agent after their use on weeds.

**The Effect of Microplastic Type on the Heart Rate of Filial Generation D. magna**

Donya Darawcheh

Microplastics are a persistent issue in the environment as they have had hundreds of years to form as much as they do right now. Due to this long period of development, marine organisms have consumed microplastics, which along with the inhalation of microplastics and consumption of bottled water has led to microplastics being found in humans. Microplastics have been shown to have negative effects on the cardiovascular and reproductive systems separately, however, not much has been done to look at how transferred microplastics can affect organ systems in offspring or how different microplastics types can affect these results, which is what this project aims to analyze. It was hypothesized that the smallest size of microplastic and polystyrene microplastics would decrease the heart rate the most. So far, polyethylene and polypropylene suspensions of 1µL/mL and 0.2µL/mL were administered to D. magna for an acute period of 24 hours and a chronic period of 48 hours with their heart and mortality rates being recorded each 24 hours. Both polymers of concentration 1µL/mL and polypropylene of 0.2µL/mL were found to significantly decrease the heart rate in acute exposure, as well as all suspensions having significantly decreased heart rates compared to day 0 in chronic exposure with polyethylene 1µL/mL having a 20% survival rate. These results provide evidence that microplastics can affect the heart rate and life expectancy of an organism, so it would be worthwhile to continue to investigate how these effects translate to polystyrene and different microplastic sizes in filial generation organisms.

**A Novel Approach to Reducing Racial Bias in Pulse Oximetery**

Ruthberly Saint Rose

This experiment aims to determine and reduce racial bias in pulse oximetry by incorporating green light. Pulse oximeters are a plastic clamp placed on a patient's finger that utilizes red and infrared light to measure the blood saturation rate and heart rate of the patient based on how much light is absorbed. Oxygenated blood absorbs more infrared light, while deoxygenated blood absorbs more red light. But, in those with darker skin, melanocytes that produce the skin-darkening pigment melanin disrupt the transmission of infrared light through the skin; therefore, overestimating their blood saturation rate. One solution to this issue would be the inclusion of a green light that would measure blood saturation rate by reflecting off the skin rather than being transmitted through it.

In my experiment, involving thirteen participants with diverse skin tones, I was able to compare the differences in heart rate using a pulse oximeter with and without green light, alongside heart rate measured by hand. For the results of this experiment, I discovered evidence of racial bias among both treatments, as the difference between the two treatments and the heart rate found by hand increased the darker a participant's skin tone was. Overall, green light did not reduce racial bias in the pulse oximeter I used, as the heart rates found by both treatments lacked consistency and had a skewed distribution, with the standard deviation being higher than the mean for each cohort of participants.

**Project VecotorScan**

Brendan Maher, Thomas Johnson

Wolbachia is a widespread intracellular bacterium that infects many arthropod species and can influence host reproduction and disease transmission. In this biotechnology project, we investigated the presence of Wolbachia in local arthropod wildlife. Arthropod specimens were collected from the local environment, and genomic DNA was extracted from each sample. Polymerase chain reaction (PCR) was used to amplify Wolbachia-specific genetic markers. Gel electrophoresis was then performed to visualize the PCR products and determine whether the arthropod samples tested positive for Wolbachia infection. The results indicated that some arthropod samples were positive for Wolbachia, demonstrating its presence within the local arthropod population. This study highlights the usefulness of molecular biotechnology techniques for detecting Wolbachia and contributes to a better understanding of its distribution in local ecosystems.

Pioneer Charter School of Science II (PCSS-II)

**Evaluating the Biological Safety of Red 40 versus Beetroot-Derived Natural Colorant Using C. elegans**

Kritika Amaranath

Artificial food dyes, including the petroleum-based Allura Red (Red 40), are widely used in processed foods, yet there is little knowledge of their effects. In this study, we examined the impact of Red 40 on development, reproduction, and behavior using the model organism Caenorhabditis elegans, and compared it's effects with beetroot powder as a natural colorant. Wild-type worms were exposed to the dyes and analyzed assays recording  locomotion, pharyngeal pumping rate, egg-laying, egg-hatching, and presence of male progeny.

C.elegans exposure to 1% Red 40 resulted in effects such as, reduced egg production, less pharyngeal pumping, less locomotor ability, lower egg-hatching rates, and a higher presence of male progeny compared to control. The results suggest potential developmental toxicity, reproductive stress, and the disruption of chromosome segregation.Contrasting the exposure to 1% beetroot powder which had no significant differences from control groups.

These findings show that Red 40 has broad effects on processes in C. elegans, while natural dyes displayed safety under the tested conditions. This shows potential advantages of natural alternatives over petroleum-based synthetic food dyes

Brockton High

**Lignification in Schlumbergera Supports a Structural Rather Than Localized Reinforcement Role**

Isabelle Tao

Succulent plants store water in specialized tissues, meaning they require adaptations that allow them to balance water storage with mechanical support. Lignin is a key structural polymer in plant cell walls that is associated with mechanical reinforcement. This study investigated whether lignification in Schlumbergera, an epiphytic succulent, follows biomechanical reinforcement patterns based on mechanical stress.

Segments from basal, primary, and secondary stems were sectioned and stained using Safranin O and counterstained using methylene blue to identify lignified tissues. Cross-section images were analyzed using ImageJ.JS to find the percentage of lignified area. Linear regression analyses were performed to examine relationships between lignification and distance as well as between lignification and normalized distance along the stem. One-way ANOVA tests were used to compare lignification within segments and across stem types.

Based on the analysis done, no meaningful relationship was found between lignification and junction proximity ($R^2 = 0.0029$) or between lignification and normalized distance along the stem ($R^2 = 0.0049$). No significant difference was found within segments ($p = 0.699$). Lignification differed significantly among stem types ($p = 0.034$), with basal stems showing the highest levels of lignification

These findings suggest that lignification in Schlumbergera is not primarily driven by localized mechanical stress, but instead reflects broader structural roles.

Wachusett Regional High

**The Effect of Glow-in-the-Dark Microplastics on the Growth and Fluorescence of Hydroponically Grown Mint Plants**

Lucia Cranson

Microplastics are an increasing environmental concern because they are found in soil, water systems, and agricultural environments, where they may interfere with plant growth and food production. This experiment investigated the The Effect of Glow-in-the-Dark Microplastics on the Growth and Fluorescence of Hydroponically Grown Mint Plants. Studying hydroponic systems allows for controlled observation of how microplastics may affect plant physiology without interference from soil variables. The research question guiding this project was: Does the presence of glow-in-the-dark microplastics in a hydroponic solution affect the growth rate and fluorescence of mint plants? It was hypothesized that mint plants exposed to microplastics would show reduced growth and increased fluorescence under black light due to interference with nutrient absorption and cellular processes.

To improve consistency and accuracy, healthy mint plants were purchased rather than grown from seeds. Each plant was grown in a modified hydroponic setup made from an 11-inch polar seltzer bottle, with the top portion inverted to hold the roots. Each bottle contained 473 mL of water and 2.46 mL of hydroponic plant food. Experimental plants received 0.2 grams of cut-up glow-in-the-dark plastic stars, while control plants received none. The experiment consisted of multiple trials with seven plants per group, all kept under identical light and environmental conditions. Plant height was measured every other day for one week. Fluorescence was measured by exposing the roots to a black light and recording light intensity using a Vernier Go Direct Light and Color Meter.

The expected outcome was that plants exposed to microplastics would demonstrate differences in growth rate and fluorescence compared to the control group. The results of this experiment aim to provide insight into how synthetic plastic pollution may affect plant systems and highlight the potential implications for agriculture and environmental sustainability.

**An Analysis on The Optimal Fruit to Promote Drosophila Longevity**

Samuel Ogbu

The goal of this experiment was to determine the optimal fruit for promoting Drosophila longevity. My hypothesis was that "fruit flies cultured using bananas as a sugar source will survive the longest, reproduce the most, and be larger than those cultured with apples, pears, white sugar, or no sugar." The motivation stemmed from a desire to control fruit fly activity during summer months. While it's well known that fruit flies thrive on the sugar in ripe fruits, it remains unclear which fruit best supports their lifespan, and which fruits should be avoided. In the experiment, 16 fruit flies were placed into 5 cultures with identical conditions, differing only in the sugar source: fruit mash, white sugar, or no sugar for the control group. The banana culture was the most successful, producing the highest number of flies, surviving the full two-week period, and yielding the largest individuals. Conversely, the no-sugar group performed the worst. These results suggest that among the tested fruits, bananas are the most effective at promoting Drosophila longevity. While sugar is vital to their health, nutrition, including vitamins and minerals, is equally important for producing healthy fruit flies. This outcome aligns with established scientific understanding of Drosophila nutritional needs and the role of sugar in health and lifespan.

**Plan it Mars**

Madelyn Murphy

The goal of the experiment is to see if it is possible to grow plants in simulated Mars regolith. The ability for the plants to grow in the regolith allows for future plans for space exploration to Mars. The hypothesis is: If green beans are grown in Mars regolith in three groups - "control", "organic fertilizer", and "synthetic fertilizer" then the green beans grown in organic fertilizer will be closest to the Earth soil growth, because the organic fertilizer has organic material and nutrients to support the beans grow in the nutrient-deficient regolith.

Experimentation took place over two plus months as the green beans grew. The beans were germinated in bags with paper towels before being transferred to the pots to grow under UV lights. There were three pots with Earth soil and three pots with the simulated Mars regolith. Each pot had three plants, and in each set of three had one control (no fertilizer), one organic fertilizer (fish emulsion), and one artificial fertilizer (Miracle-Gro Vegetable Mix). The experiment measures the height of the plant and the weight of the beans produced.

The expected results of the experiment predicted organic fertilizer to have the best growth. Research showed that not only does the fertilizer have a variety of nutrients, but it also has a history of supporting plant growth. The mixture contains not only the needed macronutrients but also micronutrients such as calcium, magnesium, sulfur, chlorine and sodium.  In contrast, the inorganic fertilizer only had three nutrients for the plants to use. The inorganic fertilizer has a higher risk of overfertilizing and causing overgrowth. The significant result proved that the organic fertilizer did produce and grow taller than the control or inorganic fertilizer. (Enroth, 2022)

Keywords:
Mars
Plant life on Mars
Sustainability
Regolith
Fertilizer
Fertilizers impact on plant growth

**The Effect of Microgravity on Plant Growth**
Emily Smith

**VoltMate :Transmitter and Receiver**

Fatmata Barrie

The purpose of this project is to explore whether one device can transfer power wirelessly to another, making charging more flexible and portable. The question investigated was: Can a phone or similar device effectively send power to another device using wireless power transfer technology?

My background for this project is that I was just curious about how to send power from one device to another if possible. I had the idea last summer. There are many places in the world that struggle with having power. As an African born there, having power for your phone can be a struggle sometimes. By starting now and making my own project I can create a change for others who are in need and just curious about it. Even though this would need more work in the future this is just the start for me.

I hypothesized that if two coils are aligned closely and powered correctly, then power can be successfully transferred from one device to another. To test this, I used a wireless power transmitter coil connected to a 5V power source and a wireless receiver coil connected to a second device, placing them close together to allow electromagnetic induction. Data was collected by measuring whether the receiving device showed charging activity and by observing stability during tests. The results showed that the receiving device charged when aligned properly, but the efficiency decreased when the coils were farther apart or misaligned.

This experiment demonstrates that device-to-device power transfer is possible, though improvements in stability and efficiency are needed for everyday use.

**Self-Supervised Permutation and Interpolation Based Noise2Noise Denoiser (SPIN) for Voltage Imaging**

Derek Li

High-speed voltage imaging allows scientists to record the subthreshold activity and action potentials from several neurons at once. However, because action potentials occur over very short time intervals (1-5 ms), camera speeds must be quick (kilohertz frame rate) which reduces photons per frame and results in low signal-to-noise ratios (SNR). This makes it difficult to distinguish biological activity from noise, causing traditional image denoisers to misidentify action potential signals as noise. I developed SPIN, a self-supervised permutation and interpolation-based Noise2Noise denoiser designed for low-SNR voltage movies. SPIN first interpolates movies in time, then permutes the data into pseudo-paired stacks that contain the same underlying signal but different noise, allowing a 3D U-Net to be trained without clean targets. I implemented the pipeline in Python and TensorFlow and tested it on both simulated voltage imaging data with a ground-truth reference and experimental recordings from Voltron2-JF525 labeled rat cortical neurons. In simulation, SPIN recovered spatial structure and region-of-interest (ROI) traces revealed the action potentials much more clearly than the raw input and compared to other denoising algorithms such as SPEND. In the experimental voltage recording, SPIN increased dF/sigma from 2.56 to 9.80 while preserving fast transients and reducing temporal variance. These results demonstrate that self-supervised denoising improves the interpretability of low-SNR kilohertz voltage data, enabling more reliable measurements. That makes the method potentially useful for neuroscience, chemical analytics, and other fields that rely on high-speed imaging or sensing modalities where rapid acquisition often results in low signal-to-noise measurements

Keywords: Voltage Imaging, Self-Supervised Denoising, Signal-to-Noise Ratio (SNR), Action Potential Detection

Northfield Mount Hermon School

**UV Protection and Antimicrobial Hydrogel of Sodium Alginate/ Nano Silica-Zinc Hydroxide and Its Biodegradable Nanocomposite Film**

Frank Nguyen

Excessive ultraviolet exposure and microbial contamination remain major concerns in designing safe, breathable wound dressings and cosmetic patches. Although alginate hydrogels and zinc-based additives are widely used, conventional alginate films often provide limited UV protection and weak intrinsic antimicrobial properties. Unlike ZnO, which can generate reactive oxygen species under UV exposure and potentially irritate damaged skin, zinc hydroxide offers a gentler, easily processable alternative. In this study, a sodium alginate hydrogel film was enhanced with a silica–zinc hydroxide core–shell nanofiller. The silica core acted as a stabilizing scaffold, improving zinc dispersion and confining UV□shielding and antibacterial activity within a uniform inorganic phase rather than free ZnO particles. This configuration produced flexible hydrogels capable of strong UV attenuation and short-term bacterial inhibition at relatively low mineral content. Structural and spectroscopic analyses verified the formation of the intended SiO□–Zn(OH)□ phase and its homogeneous distribution in the alginate matrix. These results link the composite's nanoscale organization to its optical, mechanical, and antimicrobial performance. Under in vitro conditions representative of skin□contact materials, the films showed near-complete UV blocking, temporary antibacterial action, and controlled swelling or dissolution in water. Such characteristics make them well suited for short-wear uses, such as protective wound dressings or daytime cosmetic sheet masks. Overall, this zinc-hydroxide–based alginate nanocomposite film and gel presents a safer and more adaptable configuration than traditional alginate–ZnO systems, achieving effective photoprotection and mild antimicrobial function while remaining biocompatible and easily removable.

Keywords: Material Science, Polymer, Nanomaterials, UV-protection, Antimicrobial, Biodegradable film, Biomaterials.

Dana Hall School

**Esterified Tea Waste Hard Carbon for Sodium-Ion Batteries**

Sian Che

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Abstract

Sodium-ion batteries are considered a promising alternative to lithium-ion systems due to their low cost and abundant resources. Biomass-derived hard carbon has emerged as a competitive anode material, with ongoing progress toward practical applications.

Compared with conventional wood-based precursors, waste tea leaves possess naturally porous structures, complex frameworks, and abundant heteroatoms, offering unique advantages for hard carbon design. With the rapid growth of the beverage industry, large-scale collection of tea waste has recently become feasible, making it a sustainable and scalable carbon source.

In this work, an esterification strategy using maleic anhydride was employed to modify tea-waste-derived hard carbon, enabling simultaneous optimization of pore structure, surface chemistry, and interlayer spacing. By controlling the reaction time, the optimized sample (2TM-1400) exhibited a well-developed hierarchical micro–mesoporous structure (8–20 nm) and enlarged interlayer spacing. Electrochemical results demonstrate that 2TM-1400 achieves enhanced capacitive contribution, improved initial coulombic efficiency, and stable long-term cycling performance. GITT analysis further confirms accelerated Na☐ diffusion kinetics. The sodium storage mechanism can be attributed to a synergistic adsorption–intercalation–pore-filling process.

In addition, a vacuum distillation strategy was proposed to recover excess maleic anhydride, improving reagent utilization and process sustainability. This work provides a scalable and environmentally friendly pathway for converting waste biomass into high-performance energy storage materials.

Keywords: Spent tea leaves; Esterification modification; Hard carbon anode; Sodium-ion battery

Wilbraham & Monson Academy

**Size and Distance Dependent Plasmonic Enhancement in Tannic Acid Modified Silver Nanoparticle Luminol Chemiluminescence System**

Hanming Xu

Ultrasensitive detection methods, such as Covid-19 test, often suffer from weak signal output. Plasmonic enhancement, a physical phenomenon, offers a potential solution to this limitation. In this study, plasmonic enhancement is investigated through the chemiluminescence (CL) of tannic acid–functionalized silver nanoparticles (AgNPs) in a luminol–H☐O☐ system. The effects of nanoparticle size and the time-dependent growth of a tannic acid spacer layer on CL emission are examined. Four AgNP sizes are characterized, with 82 nm particles exhibiting the strongest spectral overlap and highest emission intensity. The tannic acid spacer layer shows a positive linear relationship with time, increasing from approximately 11.1 nm to 22.7 nm. The mechanism and benefits of this spacer layer are further investigated, revealing that it functions as an optical modulator by reducing quenching and non-radiative energy transfer while optimizing plasmon–emitter coupling. Overall, this work presents a reproducible approach for investigating plasmonic enhancement in luminol systems, with implications for improving sensitivity in biosensing, forensic analysis, and nanoscale photonic applications.

Key words: plasmonic enhancement, luminol chemiluminescence, silver nanoparticles, tannic acid spacer layer, Ultrasensitive detection

**The Peel Deal: Using Varying Amounts of Acetic Acids to Strengthen Bioplastic From Banana Peels**
Kels Nguyen

https://docs.google.com/document/d/1k10E91m3MA7HtqmEJFisD5lUn-xlPXmK/edit?usp=sharing&ouid=112579214276416124781&rtpof=true&sd=true

Peel Deal: Using Varying Amounts of Acetic Acids to Strengthen Bioplastic Made From Banana Peels
Rationale (Problem)
Researching and experimenting in greater detail on banana peel bioplastics is important because it is a new topic with many benefits from its experimentation. Currently, there are approximately 20 million tons of plastic waste. Additionally, about 100 million tons of banana by-products, like peels, are negatively impacting the environment. Through my thorough research, I have found that understanding how to reuse banana peels as an alternative to plastics can significantly increase advocacy for a better environment. For instance, the bioplastics can limit food waste, reduce pollution, limit the emission of greenhouse gases, and influence a more sustainable solution to improve global warming. Although some research on bioplastics made from banana peels has been conducted, it requires further attention and development to meet market demands for creating bioplastics properly or establishing a standardized method for collecting peels for repurposing. Not only are bananas very common and affordable fruits that are found in many households, but the banana peels also offer an environmentally friendly substitute for plastics because they are biodegradable. By doing this research experiment, there will be clearer guidelines for people to help contribute to global warming in their own kitchens; this will allow banana byproducts to have a second purpose instead of being negatively polluted.

Hypothesis(es)
If the amount of acetic acid added to the banana peel bioplastic increases, then its tensile strength will increase.

Procedure
Safety
Risks: stove top, heated materials, acetic acid in vinegar, knife, blender
Safety Equipment: googles, closed-toe shoes, adult supervision when using the stove top, kitchen mitts

Experimentation
Use about 2 bananas and chop the peels into thin, small pieces
Weigh exactly 31.5g of the pieces on a digital balance
Put 200mL of water into a medium pot to boil on medium heat for 2 minutes
Add peels to the boiling water for 10 minutes
After 10 minutes, stop boiling and wait 1 minute for it to cool
Drain the water in the pot and put the softened peels into a blender
Blend the banana peel pieces with 20mL of water for 70 seconds
Pour the mixture into a fine mesh/coffee filter to remove excess water
Place the paste into an empty pot
Add 5mL of glycerin using a syringe into the pot
Add either 5, 10, 15, or 20mL of vinegar, based on the group trial
Stir the contents inside the pot for 15 seconds
Heat the mixture on medium heat for 5 minutes, then 10 minutes on low
Stir occasionally every 10-15 seconds
Turn the heat off and let it cool for 2 minutes
Pour the mixture into a tray lined with parchment paper
Spread the mixture evenly with a flat surface pressed down on it
Start a timer and air dry at room temperature for 72 hours
Remove the bioplastic and measure the thickness using calipers/rulers
Cut into equal-sized strips, 1.5 cm by 5 cm, and label them according to their group (using a piece of paper near it)
Measure by this method below:
1. Find two equal surfaces

**Analyzing How Different Tinted Glass Bottles Withstand Chemical Migration Against Solarization**

Isabella Chalmers

The purpose of this experiment was to determine which of the commonly used tinted glass bottles can best prevent chemical migration after being exposed to prolonged UV light. Colored glass contains metal oxides that range in UV blockage; therefore, it was hypothesized that the amber glass would be the least susceptible to chemical migration caused by solarization. Amber, cobalt, chromium, and clear glass bottles were coated with cadmium-based paint, filled with water, and exposed to UV-A light for 10 hrs over three weeks (3 trials). Cadmium levels were measured with a heavy metals test kit. Results showed no cadmium in the amber bottle, mixed results in cobalt, and consistent cadmium presence in chromium and clear bottles. This suggests greater UV blockage maintains structural integrity and reduces chemical migration. These results may aid packaging regulations, especially for pharmaceutical and recycled glass products.

**Molecular Insights into Ion Selectivity using Functionalized Carbon Nanotubes**

Haoze Liu

Carbon nanotube (CNT) based nanofiltration offers a promising approach for lithium recovery from brines, where selective separation of Li□ from $Mg^{2}$□ remains a major challenge due to weakened selectivity at high salinity. This study investigates how the arrangement of charged functional groups (COO□ and NH□□) within CNTs influences ion transport and selectivity, with the hypothesis that specific charge configurations can enhance selective ion permeation. Molecular dynamics simulations were performed using NAMD under controlled conditions (300 K, 20 ns, 200 bar) with a brine-like solution containing Li□, $Mg^{2}$□, and Cl□ ions, and multiple CNT charge configurations (4N, 4C, 2N2C, 2C2N) were systematically analyzed. Ion permeation counts, spatial density distributions, and ion trajectory behaviors were evaluated to quantify transport characteristics across different systems. Results show that the 4N configuration exhibits the highest ion permeation, while the 4C configuration shows almost no permeation, with $Mg^{2}$□ consistently demonstrating the lowest transport due to stronger electrostatic interactions; additionally, ions form “sandwich-like” clustered structures near functional groups that hinder transport. Overall, these findings demonstrate that negatively charged COO□ groups have a stronger impact on ion transport than NH□□, providing molecular-level insights that can guide the design of more selective nanofiltration membranes for lithium recovery.

**Fudge: How Specific Heat Capacity Affects the Phase Change of Heavy Cream**

Tyler Strazzullo, Mark Kudarauskas, Seamus Kehoe

Recipes, like to make ice cream, rely on material properties to form desired consistencies. Specific heat capacity is the amount of energy required to change the temperature of a substance by 1 degree Celsius, which affects properties like freezing point. We proposed that the incorporation of other substances, like fudge, would decrease the rate at which the ice cream crystallized as measured by viscosity testing at various times. How greatly the rate would be affected is linked to the heat capacity of the material. One of our findings was that the specific heat capacity of homemade fudges was very similar to that of chocolate. In our procedure, first we found the specific heat capacities of the fudges we used by heating them to a known temperature, then placing it in room temperature water to find the change in temperature. We used that to find the specific heat of fudge. After finding this for the fudge, we made a mixture of heavy cream, sugar, and whole milk to make ice cream. We put the mixtures in bags and added the fudge, then shook the bags in ice water with salt for intervals of 10 minutes. Our work can continue into the future by having future experiments that find the optimal specific heat capacity of fudge for making ice cream.

**To Glow or Not To Glow, The Activation Energy of UV Reactive Paints**

Evelyn Ramirez-Frazier, Miles Arden

Phosphorescence can be mediated by impurities in nearby materials. The properties of paint can affect the phosphorescence of UV reactive pigment that is mixed into the paint. We started our experiment by making acrylic, watercolor, and oil paint from scratch. To do this we mixed our UV reactive europium pigment powder with water and acrylic medium, linseed oil, and gum arabic solution and honey, for each type of paint. After making the paints, we painted each on to paper, put it under a UV light, and checked the luminance after five seconds for different temperatures. We found that the higher the temperature of the sample, the faster we found the peak of the luminance, and the faster that the luminance, or the glow, died down. We also found that our acrylic paints were the most stable but also had the lowest activation energy, and our oil paints stood out with the highest activation energy. Our watercolor paints had a slightly higher activation energy than acrylic, however the calculated activation energy may not be completely accurate because the peak of the highest temperature measurement was likely reached before we took our measurements. UV reactive paint can be beneficial for safety in low light conditions, such as showing the edge of stairs in the dark. UV reactive paint can also be used in artwork.

**Using Heat and Vibration to Relieve Menstrual Pain**

Yvonnie Li, Kellyn He

Women and teen girls experience menstruation every 4-5 weeks and it often arrives with cramps and aches. Heating the abdomen is one way to relieve the pain that does not use medicine. Our first experiment's purpose is to determine the efficiency and longevity of each exothermic reaction with different reacting compounds including sodium acetate, sodium carbonate, and calcium chloride. This experiment was done by observing the temperature changes on 30-second and 1-minute intervals of the process of phase changes of the compounds in calorimeters. The second part of this experiment was to change the mass of each compound to observe the relationship between mass and final temp. The final results concluded that sodium acetate was the best chemical to be used in heat packs. Using this outcome, our second experiment's purpose is to determine how the ratio of ethanol and water would affect the crystallization process of sodium acetate in a heat pack. We will be doing this experiment by adding different amounts of ethanol to the same amount of supersaturated sodium acetate solution to observe when the crystallization process happens. We will have a control group that contains no ethanol. Our final results should show the optimum, or better, combination of ethanol and water in a reusable heat pack containing a supersaturated solution of sodium acetate to undergo the crystallization process once the activator, or metal disk, in the heat pack is bent.

**Chemistry: Power Peel Plastics**

Clemerlin Crespo-Alvarado

The objective of this project was to use potato starch to create biodegradable plastics with varying amounts of glycerol to study their physical and chemical properties. Three different samples of plastic were made with three different amounts of glycerol. The samples respectively had 5 ml,10 ml, and 15 ml of glycerol. The plastic was made with potato peels, vinegar, glycerol, and water. The peels were cut and blended with water, then left alone for the starch to settle at the bottom of the beaker. After, the mixture in a beaker was placed on top of a hot plate, where it was mixed until it thickened. Next, the mixture was poured on a sheet of aluminum and left to dry at room temperature. The results of the first trial with 5 ml of glycerol were that the plastic was brittle and stiff. The second one, with 10 ml of glycerol, was flexible and easier to handle, while the final trial, with 15 ml of glycerol, was the most flexible of all of them. The plastic got softer because the glycerol was acting as a plasticizer that integrates between the polymer chains, making it move more freely. Before experimenting, it was thought that more glycerol would make the plastic feel more rubbery and smooth. The results do support my hypothesis. The results indicate that the hypothesis was correct. Next time, different types of peels, like fruit or vegetable peels, will be investigated to determine if the data will also support this hypothesis.

**Chemical Analysis of Stagnation in Pipelines on Water Quality and Effectiveness of Subsequent Treatment with Crassostrea virginica**

Jacob Lazar, Samhitha Shreesha Pai

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Water stagnation within building pipelines raises concerns for water departments regarding potential depreciation in water quality over time. Many modern filtration mechanisms come with significant detriments (e.g. overpurification and cost). The biological filter-feeding mechanism of the Eastern oyster (C. virginica) may provide a promising scaffold to model a water filter which is effective in reducing detriments caused by stagnation. We took a stratified random sample of local buildings and control samples, and tested their respective water samples for pH, TDS, conductivity, turbidity, heavy metal presence, alkalinity, TOC, and fecal coliform presence. The samples were treated with C. virginica and the tests were taken a second time. It was found with 99% confidence that stagnation had a significant detrimental impact on pH and turbidity, and had no measurable impact on TDS, conductivity, heavy metal presence, alkalinity, and coliform; although, difficulties in testing resulted in inconclusive data for conductivity and heavy metal presence. It was found with 95% confidence that short-term stagnation has a beneficial impact on TOC levels. The result of C. virginica filtration was a measurable stabilization of pH and reduction in turbidity, indicating that oyster filtration is a viable solution for measured effects of stagnation. Contrary to our hypotheses, TOC was found to decrease after treatment for minimally stagnant samples (residential) and increased for more stagnant samples (commercial and public). Moving forward, more complex water quality metrics should be tested, and the results should be put to practice by fabricating a functional water filter.

Keywords: Water quality, pipe stagnation, Eastern oyster, pH, TDS, conductivity, turbidity, heavy metals, alkalinity, TOC, kinetic modeling, UV-photolysis of hydrogen peroxide, fecal coliform, statistical testing

**Stopping Stones in Their Tracks: A Comparative In-Vitro Analysis of Natural Inhibitors of Calcium-Oxalate Kidney Stone Formation**

Anish Gupta

Calcium-oxalate kidney stones make up nearly 80% of all kidney stones, and their prevalence is rising due to changing diets. While several natural substances are believed to inhibit crystal formation, there are few studies that directly compare effectiveness under controlled conditions. This study investigated whether punarnava (Boerhavia diffusa), coconut water, lemon juice, and Cissus quadrangularis could inhibit calcium-oxalate nucleation and aggregation. It was hypothesized that lemon juice, coconut water, and punarnava would reduce crystal formation by at least 20%, while Cissus quadrangularis would show inhibition within 15 percentage points of the strongest treatment. To test this, calcium chloride and sodium oxalate solutions were combined to simulate stone formation. Each inhibitor was tested in replicates of 15 at an 80% concentration (v/v), with distilled water as the control. After incubation, precipitates were filtered, dried, and weighed to derive mean mass, inhibition percentages, and statistical significance using unpaired t-tests. The two most effective inhibitors were then tested at a 50% concentration (v/v) to evaluate concentration impact. At 80%, all treatments reduced precipitation compared to the control ($p<0.05$). Punarnava produced lowest mean mass (~7.33 mg) and highest inhibition (~59.9%), followed by coconut water (50%). Lemon juice and Cissus quadrangularis showed moderate inhibition. At 50%, punarnava had no significant impact and coconut water promoted precipitation. These findings demonstrate that inhibitor composition and concentration influence crystallization. Future research should identify optimal concentrations, isolate inhibitory phytochemicals, and test effectiveness under in-vivo conditions to determine clinical potential for kidney stone prevention.

**Modeling Annihilator to Sensitizer Ratios for Optimal Light Intensity in TTA Upconversion**

Aishani Ghosh

Triplet-triplet annihilation upconversion (TTA-UC) is the organic chemical process of upconverting low-energy light to high-energy light. This is done through two chemicals, the annihilator and sensitizer. The ratio of the annihilator to the sensitizer affects the efficiency of the system and primarily the intensity of the light produced. The optimal ratios for TTA-UC pairings are commonly known, but their effect on light intensity has not been well modeled.

The goal of this experiment was to test a variety of ratios for an annihilator-sensitizer pairing and model it on a graph, created to predict the light intensity from a given ratio. 6 different ratios of a TTA-UC system were observed using a spectrofluorometer to find how light intensity changes with an increasing amount of annihilator. It was found that doubling the amount of annihilator from 1:50 to 1:100 created a 2.52 times increase in peak light intensity. However, increasing the concentration to 1:200 resulted in no light intensity being produced.

It’s clear that light intensity and concentration do not have a linear relationship, but rather one that increases at first, then quickly drops off due to inefficiency in the system. This relationship was modeled with a quartic function, resulting in a R^2 of 0.9031.

Understanding how specific ratios affect light intensity is important because it helps researchers design experiments and apply TTA-UC to real-world applications. In solar panels, TTA-UC can be used to upconvert near-infrared light to a higher-energy light, which is more efficient for solar panels to absorb. Next steps include refining the model, expanding it to apply to different TTA-UC pairings, and testing the effect on concentration on peak light intensity.

Keywords: TTA-UC, sensitizer, annihilator, upconversion, wavelength, light

Grafton High School

**From Pollution to Power: Testing Tin-Copper Nanoflowers to Turn CO2 into Formate**

Harit Sree Charan Suraparaju

In an electrolytic cell, electrons flow from the anode (oxidation) to the cathode (reduction), driving the conversion of carbon dioxide and water into formate at the cathode, while hydroxyl radicals are oxidized into water and oxygen at the anode. This project investigates how electrode surface area affects formate production by comparing copper, tin, and tin-plated copper electrodes. Tin-plated copper forms three-dimensional “nanoflower” structures during electroplating under the right voltage and pH, increasing surface area and providing ideal active sites. Tin offers efficient adsorption due to its p-block properties, while copper provides conductivity and electrons to the tin surface. Copper alone is less efficient, as its adsorption is too strong to facilitate the reaction effectively. This experimentation found that the copper plated with tin produced the most formate and is therefore the most efficient.

**Structure-Guided Computational Design of Bispecific Complement Engagers (BiCE) Molecules Targeting NCAM1 and CD64 for Neuroblastoma Treatment**

Aditi Palle

**Creating and Utilizing Metal-Organic Framework Technologies in Carbon Dioxide Filtration to Reduce Factory Emissions from Fossil Fuel Burning**

Lana Nguyen, Emerson Ohashi

Because of global warming, it is imperative to reduce factory greenhouse gas emissions, which accounts for over 60% of total emissions. Current filtration technologies use activated carbon filters (ACFs) to absorb gases.
The alternative, however, metal-organic frameworks (MOFs), are crystalline, porous structures made from organic linkers and metal salts that have applications in gas filtration. The focus of this project is to explore and build upon filter technologies to reduce greenhouse gas emissions.

The most suitable organic linker and metals were 1,3-benzenedicarboxylic acid, $Cu^{2+}$ and $Fe^{3+}$. We used reflux synthesis to create the MOFs, and we predicted they would have a square planar and an octahedral structure respectively.

We hypothesized that using $Fe^{3+}$ would result in more effective $CO_2$ filtration than $Cu^{2+}$. Our reasoning was that an octahedral pattern had a greater surface area, as molecules with octahedral geometry possess six ligands and occupy a greater volume.

To test the MOFs, we created a device that releases $CO_2$ into a controlled environment and measures the ppm after filtration. We compared the two MOFs to a control and an ACF. We ran four trials for each filter, and found that the copper MOF was more effective than the iron. However, they were both noticeably worse than the ACF.

Our data contradicted our hypothesis, and we concluded that MOFs are not a viable solution currently to the global warming problem. For future research, we plan to use different organic linkers, metals, and synthesis methods to test a larger variety of MOFs.

**Blocking the Burn: A Comparative Study of the Effectiveness of Sunscreen**

Grace Ahearn

Ultraviolet radiation, also known as UV, from the sun can severely damage skin and contribute to skin cancer. Sunscreen is designed to block UV radiation, but different ingredients affect the sunscreen's effectiveness. This experiment studies whether mineral or chemical sunscreens are more effective and how application thickness affects protection. It was hypothesized that mineral sunscreens containing zinc oxide or titanium dioxide block more UV light than chemical sunscreens with ingredients such as avobenzone or oxybenzone. This is because mineral sunscreens deflect UV rays rather than absorbing them. Six SPF 50, water-resistant sunscreens were applied at three thicknesses (0.5mm, 1.0 mm, 1.5 mm) on plastic sheets over cyanotype paper, which is UV-sensitive paper. All six samples were exposed to natural sunlight for 15 minutes at the same time in order to control as many variables as possible. The UV protection the sunscreen offered was measured by analyzing the darkness of the developed cyanotype paper. Results showed mineral sunscreens, Thinkbaby and Babo Botanical, provided the most UV protection. Hawaiian Tropic offered moderate protection, followed by Neutrogena and Coppertone, with Sun Bum providing the least protection. These results suggest mineral active ingredients significantly enhance sunscreen effectiveness. In conclusion, mineral sunscreens were most effective against UV light, and increased thickness improves overall protection. Future research could test additional SPF sunscreens, more exposure time, thinner application, or analyzing UVA protection separately from UVB protection.

**Recovery of Dialysis Tubing After Heat Stress**

Swara Patkar, Samanvitha Vangala, Nitya Sunku

Chronic Kidney Disease affects 10% of the global population, and more than 3.5 million people rely on dialysis or kidney transplants to manage kidney failure. Dialysis depends on a semipermeable membrane to filter waste, so even small disruptions, such as heat exposure, can interfere with its function and affect the patient's well-being negatively. The purpose of this experiment was to determine whether or not cooling dialysis tubing after heat stress would revert its filtration to normal, because heat stress causes filtration to speed up. We hypothesized that cooling the tubing would either only partially restore the filtration rate or not restore it at all after heat stress. For our experiment, we placed dialysis tubing in 37 °C water for the control, 42–45 °C water for the heat□damage trial, and 25 °C water for the cooling□recovery trial, measuring how much dextrose diffused out every five minutes using glucose test strips to check filtration over time. It was in each of the conditions for thirty minutes, except the cooling was for ten minutes at first to simulate recovery, and then we placed it in 37 ºC water for thirty minutes. We compared the results from all three conditions to see whether or not cooling the tubing reverted its filtration after heat damage. While the control group had a significantly low average final concentration of 0.18%, both the heat stress and cooling/recovery conditions had a final concentration of 2%, which was the maximum concentration that could be reached. Additionally, when we performed a t-test between the final concentrations for the control condition and the cooling condition, which were the two main conditions that we had to compare, the p-value was less than 0.05, meaning that there was a significant difference. These results showed us that cooling the dialysis tubing after heat stress did not revert its filtration to normal. If cooling had reversed the damage, there would not have been a significant difference between the final concentrations of dextrose for the control and the cooling.

**KineSync (Neural Network System for Biomechanical Archetype Classification in Sprinting)**

Siddiqi Komou

For high school track athletes, sprint coaching relies on subjective visual assessment to categorize running technique. This can often times be inaccurate for more experienced sprinters who want to achieve better technique. Several variables influence running performance, with each athlete having a unique combination of those variables. Due to this, every athlete has a different optimal technique that cannot be found by eye. No data-driven framework exists to identify distinct biomechanical patterns across the full range of human running speeds. This study therefore developed a computational pipeline to discover sprint technique archetypes from biomechanical data and classify new runners into those archetypes using a neural network. First, a three-tier dataset spanning 2.5 to 12 meters per second was assembled from laboratory motion capture data, 30 biomechanical features extracted from 15 published studies, and pose estimation applied to publicly available sprint videos. Then, a physics-based inverse dynamics model estimated ground reaction forces where direct measurements were unavailable. Physics-weighted K-means clustering was then applied to the unified dataset to discover technique archetypes without predefined categories. All of that data was then fed into a feedforward neural network, implemented using only NumPy, which was then trained on the cluster labels to classify new video-derived inputs. Forward kinematics generated synthetic stick figure animations to visualize each discovered archetype. Clustering revealed four distinct biomechanical archetypes characterized by differences in stride length, contact time, vertical/horizontal force, and stride frequency. The neural network classified held-out test samples with above 80 percent accuracy. Archetypes were distributed across speeds rather than mapping strictly to sex or performance level, suggesting that technique variation is not solely explained by demographic factors. These results demonstrate that unsupervised learning can reveal interpretable biomechanical categories in sprinting and that a lightweight neural network can reliably assign new runners to these categories from video alone, offering a scalable tool for evidence-based coaching.

North Attleboro High

**The Effects of Neural Noise on the Stability of Excitation–Inhibition Driven Oscillations in a Computational Brain Network**

Ashmita Vashisth

Neural oscillations are rhythmic patterns of brain activity essential for attention, memory, perception, and sleep. They arise from the interaction between excitatory neurons, which increase activity, and inhibitory neurons, which suppress it, with precise timing enabling coordinated rhythms. This project examined how random neural noise affects the stability and synchronization of oscillations in an excitatory–inhibitory (E–I) network.

A spiking neural network model was created using the Brian2 library in Python, consisting of 80 excitatory and 20 inhibitory neurons connected probabilistically to mimic cortical networks. Noise was introduced as a stochastic term in the membrane potential and systematically increased across simulations. Network activity was analyzed using raster plots, population firing rates, stability heatmaps, FFT frequency analysis, phase coherence, firing rate variability, spike counts, gamma-band power, peak frequency detection, and automatic instability threshold identification.

At low noise levels, oscillations were stable and synchronized: raster plots showed clustered spikes, firing rates formed smooth waves, heatmaps displayed clear banding, and FFT revealed a strong gamma peak. Synchrony and gamma power were high, and variability was low. Increasing noise progressively degraded these patterns: spikes scattered, banding weakened, spectra flattened, synchrony decreased, variability rose, and the stability region narrowed. Threshold detection identified a noise level beyond which coherent oscillations could not be maintained.

These results indicate that stochastic neural noise disrupts excitatory–inhibitory timing, reducing synchronization and destabilizing oscillations. Findings highlight the importance of E–I balance in maintaining organized neural activity and provide insight into how disrupted rhythms may arise in neurological and psychiatric conditions. Computational modeling proves a powerful tool for studying these dynamics in a controlled, measurable way.

**Decoding Phenotype-Gene-Disease Networks using Explainable AI**

Navya Satishkumar

Diagnosing rare genetic disorders is challenging because many diseases share overlapping phenotypes, often leading to delayed or inaccurate diagnosis. This project uses explainable artificial intelligence (AI) to identify reproducible biological patterns linking genes, phenotypes, and diseases.

I integrated multiple large-scale datasets, including the Human Phenotype Ontology (HPO), the Functional Gene–Disease Database (FGDD), ClinVar, and Orphanet, to construct gene–phenotype networks spanning thousands of genes and traits. Using Python, I applied dimensionality reduction (PCA) and unsupervised clustering (K-means) to group genes based on shared phenotype profiles. These clusters revealed biologically meaningful categories, including neurodevelopmental, craniofacial, and connective tissue pathways.

To test whether these patterns were robust, I performed pathway enrichment and compared results across datasets. I found that genes consistently converge into core biological pathways, such as chromatin regulation and RAS/MAPK signaling, demonstrating cross-dataset reproducibility. A permutation test confirmed that the observed structure is statistically significant and not due to random associations.

To improve interpretability, I trained a Random Forest model and used SHAP (Shapley Additive Explanations) to identify key phenotypes driving gene clustering. Neurodevelopmental and craniofacial features were among the most important contributors. Network analysis also highlighted hub genes, such as FGFR2 and CREBBP, that connect multiple phenotype groups.

This project demonstrates that explainable AI can uncover biologically meaningful and reproducible patterns across independent datasets. These findings may help improve understanding of gene–disease relationships and support faster, more accurate diagnosis of rare genetic disorders.

**LLM-Driven Text Signals in Multi-Round Prediction Markets: Bayesian Updating, Fractional-Kelly Betting, and Robustness Evaluation**

Shengtao (Alex) Ding

Who Bets Smart? Classifying Participants in Decentralized Prediction Markets via Unsupervised Clustering

Prediction markets are theorized to aggregate dispersed information efficiently — but only if participants possess and act on genuine informational signals. In practice, markets contain a heterogeneous mix of rational professionals, sentiment-driven retail bettors, and random noise traders. While this three-type taxonomy (Professional, Sentiment, Noise; abbreviated P/S/N) has been proposed theoretically, no prior work has demonstrated that unsupervised machine learning can recover these latent types from observable behavioral data alone — without any ground-truth labels.

This study addresses that gap. We formalize the P/S/N framework mathematically: P-types apply Bayesian updating and fractional Kelly criterion position sizing; S-types form beliefs via emotional and political signals; N-types exhibit uniformly random belief distributions. From these theoretical primitives, we derive four behavioral features — trade count, maker ratio, market diversification, and net position size — that should distinguish the archetypes in any prediction market.

We test this on 455,941 real blockchain transactions extracted from Polymarket, the world's largest decentralized prediction market, via a custom Polygon RPC ETL pipeline. Applying K-Means clustering (K=3, selected via Calinski-Harabasz optimization) to the behavioral feature space yields a Calinski-Harabasz index of 4,757.09, indicating exceptionally well-separated clusters. Outcome-aware validation using Polymarket's GraphQL position data confirms the theoretical predictions: S-type traders achieve an accuracy of 40.0% and mean ROI of −20.0%, consistent with systematic loss from conviction-based betting; P-type traders achieve +6.8% ROI, consistent with informed, disciplined positioning. A secondary GMM comparison confirms K-Means superiority for binary-outcome financial data (Silhouette: 0.651 vs. 0.461).

These results demonstrate that the P/S/N behavioral taxonomy is not merely a theoretical convenience — it is an empirically recoverable structure, detectable through unsupervised learning on public blockchain data without any self-reported labels or surveys. This finding has direct implications for the design of prediction markets intended for socially valuable forecasting: market accuracy is not a function of mechanism alone, but of who is participating.

Keywords: Prediction Markets, Trader Clustering, Information Asymmetry, Whale Dominance, Behavioral Modeling, Blockchain Analytics

**Malaria Transmission Dynamics Modeling for Optimized Insecticide-Treated Net Allocation**

Rajarshi Mandal

There are 250 million malaria cases with 600,000 deaths annually, even though billions of dollars have been spent on insecticide-treated nets (ITNs). This project explores how to utilize the same nets more effectively by accounting for insecticide resistance, seasonal variations, and the realities of families who sometimes sell or repurpose nets for fishing to obtain food. My work combines a malaria transmission ODE model that simulates infection spread between humans and mosquitoes with stochastic compartmental dynamics, ITN decay, and environmental data. A custom reinforcement learning agent with a fixed budget allocates ITNs across many regions in mass distribution campaigns. With the same ITN budget, my State-Action Regression (SAR) model doubles the case reduction achieved by population-based allocation (11.2% vs 5.6%) and has an estimated cost of $60.44 per Quality-Adjusted Life Years gained. Model robustness was validated with ablation experiments and backward bifurcation risk analysis. In conclusion, my project proposes a framework for malaria nonprofits to reduce malaria cases without increasing annual budgets.

Keywords: Computational epidemiology; Compartmental ODE modeling; Malaria transmission dynamics; Stochastic epidemiological simulation; Reinforcement learning; Resource allocation optimization; Lyapunov stability; SHAP interpretability; Variational autoencoder (VAE); Ablation study; Insecticide-treated nets (ITNs).

Boston Latin School

**A Quantum Computational Approach to Identify Potential Pan-Cancer Metastasis Biomarker Sequences**

Brian Xu

Cancer is the second leading cause of death in America. Metastasis is the leading cause of cancer-related mortality. Identifying candidate biomarker genes could improve survival. While random forest and greedy selection typically rank or select one gene at a time, quantum computing evaluates gene combinations simultaneously through quantum superposition. I hypothesized that a quantum computing approach could identify metastasis biomarker candidates with performance comparable to classical approaches. I obtained data from the Cancer Genome Atlas (TCGA) for seven cancer types (kidney, colon, stomach, lung, breast, rectal and melanoma), supplemented with data from the Gene Expression Omnibus (~3,300 samples). I formulated the gene selection problem as a quadratic unconstrained binary optimization problem (QUBO). I solved it with a quantum approximate optimization algorithm (QAOA) on IBM's Qiskit: selecting 8 genes per cancer from ~3,000 candidates. I then compared results with exact solvers and classical techniques, validated with scaling and other analyses. QAOA matched the optimal solution across all seven cancer types, finding 11 genes missed by classical methods, with 9 potentially novel biomarker candidates. Enrichr pathway analysis revealed several map to metastasis-related pathways. QAOA also outperformed classical algorithms, producing higher AUCs for 4 of 7 cancers. QAOA demonstrated high reproducibility, with a Jaccard similarity of 0.84-1.0 across random seeds. Classifier AUCs of 0.55-0.88 across all cancer types reflected class imbalance. External validation revealed an AUC of 0.73 across GEO data. Ultimately, these results indicate that quantum computing can find biomarker candidates which classical methods miss.

**How Network Parameters Shape Neural Cascades**

Ruike Liu

Neural Cascade, Erdős–Rényi Network, Fourier Analysis, Power Spectrum, Oscillation, Periodicity, Extinction Threshold, Rhythmicity, Spearman's Rank Correlation, Inhibitory Neurons

This computational study modeled neurons as occupying three states — Resting, Firing, or Refractory — on an Erdős–Rényi random network (20,000 neurons, 200 connections each averagely) and swept two parameters: transmission probability $\alpha$ (how likely a firing neuron activates its neighbors) and recovery rate $\beta$ (how quickly a neuron exits its refractory state). Over 250,000 simulation runs, a sharp extinction boundary emerged at $\alpha \approx 0.007$, below which cascades largely died and above which they self-sustained; this transition was abrupt (86% of the extinction drop concentrated within a narrow $\alpha$ range) and entirely independent of $\beta$ (Spearman $r = -0.006$, where r measures monotonic association from −1 to +1). A rhythmicity index combining phase and shape consistency revealed that only 2.2% of surviving runs were genuinely periodic — exposing the standard spectral sharpness metric (Q-factor) as inadequate for detecting true periodicity. Among these rhythmic runs, higher $\alpha$ strongly predicted greater amplitude ($r = 0.968$), higher mean activity ($r = 0.938$), and higher rhythmicity ($r = 0.690$), while higher $\beta$ both increased rhythmicity ($r = 0.727$) and strongly shortened the period ($r = -0.975$). All findings replicated across five network topologies and five initial neuron locations (< 0.02% variance). Two experiments tested whether assigning each neuron individually randomized $\alpha$ or $\beta$ (drawn from Poisson distributions) could produce smooth oscillations; all failed, suggesting realistic neural rhythms require both deeper parameter heterogeneity and architectural changes. Ongoing extensions pursue both directions: simultaneous per-neuron randomization of $\alpha$ and $\beta$, and incorporation of inhibitory neurons.

**Optimizing T-Cell-Mediated Cancer Killing: An Agent-Based Model**

Andrew Yu

Immunotherapies for cancer aim to improve immune cell function, in order that immune cells may recognize and kill tumors. A group of immunotherapies target T-Cells, aiming to improve the patient's prognosis. However, these therapies are not always successful, and the underlying mechanisms of T-Cell elimination of tumors remains not well-understood. We developed a three-dimensional agent-based model to explore this behavior that probabilistically models cell growth, migration and interaction parameters. Through this project, we explore the influence of cytokines like IL-2 and CCL2 on T-Cell interactions and optimize the interactions between T-Cells and cancer cells to most efficiently kill tumors using modeling. The effects of increasing T-Cell killing rate, proliferation, and infiltration on their attack on tumors is still unexplored, and our study aims to fill that gap by stochastically simulating T-Cells within a cancer spheroid in order to recapitulate established research directions and identify new directions to enhance T-Cell killing of tumors. Our study found that, from greatest to least effect, increasing the killing, proliferation, and infiltration rate of T-Cells increased the clearance rate of the tumor. A 17% increase in killing rate was enough to lead to control and shrinking of the tumor, while a 15% increase in their proliferation rate was sufficient to control the tumor without shrinking it and a 30% increase in their proliferation rate was sufficient to shrink the tumor. Increasing the infiltration was only able to control the tumor, not shrink it.

Boston College High School

**Photometric Pipeline for Exoplanet Transit Detection using Ground-Based Small Aperture Telescope**

Peter Bezzerides, Talin Patel, Junior Martins

Exoplanet transits are small decreases in a star's brightness when a planet passes in front of it. These dips in light are a key method for discovering and studying planets outside the solar system. Space missions such as Transiting Exoplanet Survey Satellite (TESS) identify thousands of candidate exoplanets every year. However, these missions are often costly and largely unfeasible for anyone other than multimillion or billion dollar corporations. This creates a growing need for ground based, cheap, and reliable follow up observations. However, small aperture telescopes, which are widely available to amateur astronomers and small observatories, often struggle to detect shallow transit signals because of atmospheric interference, detector noise, and limitations in common photometric processing tools.

As a solution, a software based photometric pipeline can be used to improve the detectability of exoplanet transits using data from small ground based telescopes. Observations of known transiting exoplanets with magnitudes between 8 and 13 were collected across multiple nights using a small telescope. The pipeline processes raw time series images and generates calibrated light curves within 1 standard deviation of expected values using differential ensemble photometry, wavelet based denoising to suppress high frequency noise, and Gaussian Process regression to model atmospheric variability.

**Testing the Redshift Evolution of the Host Galaxy Mass Bias in Type 1a Supernova Hubble Residuals**

Roy Rattler III

In cosmology, Type Ia supernovae are considered standard candles for measuring distances in the universe. These standard candles provide valuable information for calculating statistics like the Hubble Constant or cosmic expansion. Studies have identified relationships between supernovae host galaxy properties, such as mass, and supernova brightness, affecting standardized values. This project investigates whether the relationship between host galaxy stellar mass and Type Ia supernova Hubble residuals changes across redshift. It was hypothesized that if host galaxy mass consistently influences supernova brightness, the relationship with Hubble residuals would remain statistically consistent at both low and high redshift. This project used data from the Pantheon+ dataset of supernovae. The data was moved from Python into Excel, then split between high redshift ($z > 0.45$) and low redshift ($z < 0.45$). Variables like redshift, host galaxy stellar mass, and standardized distance modulus were extracted to calculate Hubble residuals based on a ΛCDM cosmological model. Linear regressions evaluated correlations between host galaxy mass and Hubble residuals. Statistical Z-tests compared host galaxy mass distributions between the redshift groups. Linear regressions showed weak correlations and low $R^2$. The Z-test produced a value of 2.13 and a p-value of 0.033. These results suggest host galaxy mass alone does not significantly affect Type Ia supernova brightness residuals but that average host galaxy masses differ between low and high redshift samples. Other properties, like stellar age, metallicity, or star formation history, may play a larger role. Understanding these effects is important for improving cosmological distance measurements and refining models of the universe's expansion.

North Attleboro High

**Low Earth Orbit Active Debris Removal System using a CNN**

Akshata Serikar

Space debris in Low Earth Orbit (LEO) has become a pressing global issue that needs immediate action. It refers to non-functional man-made objects in orbit, ranging from small paint chips to entire defunct satellites. This accumulation poses significant risks due to unpredictable trajectories, leading to potential collisions with operational satellites. Even small objects can cause catastrophic damage; for example, a paint chip once damaged a satellite's multilayered glass, stranding astronauts for six months. Such incidents are rising, fueled by Kessler Syndrome, where collisions generate thousands of debris fragments.

Also, Space agencies do not track debris smaller than 10 cm, the most hazardous size, which can severely impact critical satellites, including communications, GPS, and military satellites, all valued at billions, and essential to society. Existing Active Debris Removal (ADR) systems, developed by NASA, ESA, and other agencies, target larger debris, such as rocket stages, but overlook smaller, untracked fragments identified as particularly dangerous.

My project aims to create an ML model that is able to identify debris through object detection and real-time classification and trigger an Arduino-based prototype ADR to validate the AI model. This autonomous system will utilize a camera to capture live feeds processed by an onboard computer equipped with the trained AI model. It will analyze debris based on size, functionality, trajectory, and rotation to determine capturability. The system will employ a net with a drawstring mechanism to securely retrieve debris, addressing a critical gap in current mitigation efforts and presenting a solution to the growing threats in our space environment.

Boston Latin Academy

**Detecting and Modeling Prebiotic Signatures in Exoplanet Atmospheres**

Arseny Yuzhakov

The identification of chemical conditions that enable the emergence of life is a central question in modern astrophysics. While exoplanet atmospheres have been widely studied, the presence and evolution of prebiotic signatures—spectral indicators of molecules relevant to early chemical pathways—remain largely unexplored in observational data. In this study, we investigate atmospheric signatures including water ($H_2O$) alongside candidate prebiotic species such as hydrogen cyanide (HCN), formaldehyde ($CH_2O$), and acetylene ($C_2H_2$) using transmission spectroscopy and planetary datasets . By analyzing spectral features in conjunction with planetary properties such as equilibrium temperature, surface gravity, and stellar irradiation, we identify conditions under which these signatures may be detectable. Building on this, we implement a simplified photochemical modeling framework to simulate how these signatures evolve over time under varying atmospheric and stellar environments. This enables us to move beyond static detection and instead evaluate when and where prebiotic chemistry is most likely to emerge. Our results aim to constrain the detectability of prebiotic signatures, establish relationships between planetary characteristics and chemical behavior, and provide a framework for prioritizing future exoplanet targets in the search for the building blocks of life.

**Using Machine Learning for Exoplanet Detection**

Vaanya Ahuja

Exoplanet radius is a key observable that supports comparisons across planetary populations and informs interpretations of composition, atmospheric retention, and potential habitability. This study investigates whether a planet's radius can be accurately predicted using only basic catalog parameters describing the host star and the planet's orbit. A cleaned subset of 17,781 confirmed planets from NASA's Exoplanet Archive was assembled using six numerical predictors: orbital period, semi-major axis, system distance, and host-star mass, radius, and effective temperature. We compared a linear baseline (Ridge regression) with two non-linear tree-based models (Random Forest and XGBoost) and evaluated performance on a held-out test set using $R^2$, RMSE, and MAE. Exploratory analysis showed weak pairwise correlations between planet radius and individual stellar properties, indicating that multivariate and non-linear interactions are important. Tree-based models substantially outperformed the linear baseline; XGBoost achieved the best accuracy ($R^2 = 0.765$, RMSE = 0.527 Earth radii). Feature-importance analysis suggested that orbital period and system distance were strong predictors, highlighting both astrophysical structure and selection effects in discovery catalogs. Overall, the results demonstrate that simple catalog features contain enough information to predict radii for many planets, while also emphasizing the need to interpret model drivers carefully due to observational bias and feature entanglement.

**Increasing the Accuracy of Exoplanet Detection and Classification via the Aitchison-Partal Exoplanet (APEX) Detection Machine Learning Pipeline**

Caleb Aitchison, Neva Partal

Interpretation and analysis of satellite data are either a long-winded, manual chore or require extensive digital computation. Building a lightweight machine learning pipeline to classify exoplanets based on transit light curves and filter stellar variability would make it more accessible and enable data analysis across a wide range of datasets, provided they are processed into proper time windows. A convolutional neural network (CNN) pipeline analyzes time-series data windows as they are presented visually, prepared by a program using the LightKurve library, and can differentiate between stellar noise and true transits, since the CNN can isolate unique geometric signatures. Interpretation and accuracy are currently limiting factors in exoplanet detection, and this pipeline would benefit astrophysical research when identifying new exoplanets compared to pure ML. The proposed model focuses on eliminating errors caused by stellar activity, such as flares, star spots, or stellar winds, while keeping its accessible profile. Implemented in PyTorch, with two convolutional, one pooling, and two fully-connected layers, the model has learned to identify transits in light curves available through NASA's Exoplanet Archive for the Kepler Satellite, which is downloaded, sectioned by a standardized time window, folding the time-series data, removing NaNs, and normalizing flux. To date, the model has achieved an average accuracy of 96-99%, as confirmed by the data labels in the archive. Furthermore, five identified exoplanets are manually analyzed using physical calculations to assess their habitability, comparing their planetary and orbital radii and equilibrium temperatures against the Habitable Zone (HZ) criteria for future human exploration.

Dover-Sherborn Regional High

**Rescue Reach: A Modular AI-Enabled Robotic System for Disaster Search and Rescue**

Veronika Wang

Natural disasters often create environments that are unstable, unpredictable, and dangerous for human responders, limiting the speed and effectiveness of search and rescue operations. Rescue Reach is a modular, AI-enabled robotic system designed to augment human disaster response by providing adaptable physical assistance and intelligent decision support in hazardous conditions. This project presents the design and evaluation of a modular robotic platform capable of supporting multiple configurations tailored to specific rescue tasks, such as debris stabilization, reach extension, and victim assistance. The system integrates artificial intelligence algorithms with sensor inputs (simulated and physical) to analyze environmental conditions, assist with task prioritization, and improve response efficiency. Software simulations and controlled prototype testing were conducted to assess system performance, modular adaptability, and algorithmic accuracy under varied disaster-inspired scenarios.

Results demonstrate that modular configurations significantly improve task flexibility, while AI-assisted decision logic enhances response efficiency and consistency compared to purely mechanical approaches. The system's modular architecture allows components to be reconfigured rapidly without redesigning the entire platform, supporting scalability and real-world applicability. Rescue Reach advances disaster-response robotics by transitioning from isolated mechanical assistance to an integrated human-robot collaboration framework, emphasizing adaptability, safety, and intelligent support. This work highlights the potential for modular AI-driven systems to reduce responder risk while improving operational effectiveness in disaster search and rescue.

St. John Paul II High School

**Algorithmic Classification of Classical Piano Music by Composer**

Jamison Ballou

While broad genre classification of musical compositions has advanced substantially, identifying the composer of a classical piece from limited samples remains challenging. In this research, a multimodal deep learning classification tool was developed using 676 curated audio (WAV) and MIDI high-fidelity recordings of professional performances from twelve classical composers in the MAESTRO dataset. From each audio file, Mel spectrograms were generated and used to train a convolutional neural network (CNN). Numerical features computed from both audio and MIDI data — quantifying pitch distribution, rhythmic variation, polyphony, and articulation — were processed by a bidirectional LSTM and deep neural classifier, whose output was concatenated with the CNN embedding to produce the final classification. All features were extracted over three intervals — at the beginning, midpoint, and end — to capture melodic development and continuity over the course of each composition. The system was evaluated through four experiments of increasing complexity: distinguishing between two contrasting composers (F1 = 1.000), two stylistically similar composers (F1 = 0.909), the five most represented composers (F1 = 0.836), and finally all twelve composers with more than 25 works (F1 = 0.406). F1 score was used to assess performance accounting for class imbalance in the dataset. Performance in the first three trials exceeded the target F1 of 0.7. Degraded performance in the 12-composer task was attributable to limited dataset size rather than algorithmic complexity. Additional analyses qualitatively examined classification performance across stylistic periods (i.e. Baroque, Classical, and Romantic) and geographical regions (e.g. Italy, France, and Russia).

**AI's Ability to Answer Questions Spoken in Different Accents**

Thomas Fagan

AI is continuously growing larger, therefore if humans understand AI, then they will be able to utilize it better. AI uses a five step process to answer questions, and with that process, AI has the unique ability to learn from its own mistakes. This experiment aimed to determine how effectively digital assistants are at answering questions that are spoken in different accents. To test the hypothesis that a digital assistant is more effective when it is located in the region that the accent originates from, a VPN was used to change the location while asking the digital assistants to answer questions spoken in different accents. The results showed that the digital assistants responded better to questions that were spoken in different accents when they were located in the USA, instead of the region of where the accent originates. Based on the data that was collected, the hypothesis was rejected. This suggests that location does not play a major role in the digital assistance's effectiveness of answering questions with different accents.

Pope Francis Preparatory School (Springfield)

**Body Posture and First Touch Performance in Soccer: Automated Detection and Scoring**

Surya Veeranna

In soccer, a first touch is a crucial determinant in ball retention and attacking progression. Despite the importance of the first touch, limited ways to assess first touches objectively and quantitatively to improve performance exist. This study aimed to create a low-cost system to evaluate first touches under a fixed, single-camera broadcast constraint. Compared to professional systems costing thousands of dollars, this approach is extremely cost-effective and allows resource-limited teams to allocate money toward other necessities. The study used a sample size of 139 touches taken from 40 competitions and leagues from around the world. YOLOv8 was used to automatically measure each touch for speeds and distances in normalized units (which avoided perspective distortion when using meters). Clips were then manually annotated for categorical variables such as knee flexion maintained through contact, body lean direction, and body open. Two raters were additionally used to ensure objectivity for the three biomechanical categories. Body lean achieved a Cohen's Kappa of 0.82, indicating near perfect agreement, and knee flexion achieved a kappa of 0.61, showing substantial agreement. However, the body open variable achieved a rate of 0.41, meaning there was only moderate agreement beyond chance, which shows that future definition refinement and clarity could be possible. To further investigate the effects of biomechanical actions, a logistic regression model was developed in Python. The model showed non-forward/neutral lean having the greatest positive association with touch success (>=80 score), followed by maintained knee flexion, and finally an open body. In a second logistic regression model, PPDA/Passes Per Defensive Action (a metric used to quantify a team's pressing intensity; lower PPDA = more intense pressing) was used to observe its interaction with body openness. The interaction of an open body and PPDA had a negative interaction coefficient, indicating the impact of an open body decreasing as PPDA increases, showing that an open body trends to be more impactful on score in high pressure environments. The p-values in the study (>0.05) prevent the results from being declared as statistically significant, highlighting the complexity of evaluating and modeling first touch performance where noise and other contextual variability is high.

**Incorporating Differential Geometric Features into Deep Learning Models for Lung Cancer Screening**

Shaun Ng

Lung cancer remains the leading cause of cancer-related deaths worldwide, and its survivability depends strongly on early diagnosis, which is difficult due to the lack of obvious symptoms. Although low-dose computerized tomography (CT) screening can detect lung cancer, its implementation is limited by time-intensive image interpretation and high false positive rates.
Recent advances in artificial intelligence, particularly convolutional neural networks (CNNs), have produced accurate models for predicting lung nodule malignancy, but often operate as “black-boxes,” lacking interpretability. By incorporating differential geometric features, this work aims to improve both performance and interpretability, augmenting deep learning models with domain knowledge.
Using CT scans from the publicly available LIDC-IDRI dataset, segmented lung nodules were converted into three-dimensional simplicial meshes using the marching cubes algorithm. From these, nodule morphology was distilled into differential geometric, curvature-based features such as spiculation and lobulation, which are associated with malignancy. These mathematically derived descriptors were compiled into a feature vector and used diagnostically via a generalized metric learning vector quantization (GMLVQ) model.
This project demonstrates that an interpretable, geometry-based GMLVQ model can achieve performance (~87.5% accuracy on LIDC-IDRI) comparable to “black-box” neural networks while providing transparent, quantitative malignancy scores. Combined with UNet-based segmentation, this framework offers a more interpretable and mathematically grounded approach to lung cancer screening.

KEYWORDS:
Lung cancer, malignancy, nodule morphology, artificial intelligence, neural network, machine learning, computerized tomography, differential geometry, calculus, curvature, manifold, computer science, algorithm.

**TheraBee**
Finnegan Sommer, Olutayo Oyewusi

The global mental health crisis highlights the urgent need for more accessible and accurate ways to screen for mental health conditions, especially as demand increases and professional resources remain limited. This project aims to develop an intelligent support tool powered by advanced language technology that aligns with established mental health guidelines and complements existing practices. This tool will provide clinicians and individuals with a precise, easy-to-understand, and fair platform for mental health screening and personalized help.

TheraBee, utilizing the data in the Diagnostic and Statistical Manual of Mental Disorders(DSM-5), can detect and map user symptoms, as well as their severity and duration. Using prompt engineering[1], TheraBee maps user symptoms to DSM-5 criteria through natural conversation. Response parsing handles inputs, while hyperparameter[2] tuning expands LLM creativity and exploration. By autoregressively3 comparing the user's conversation with DSM-5 guidelines and generating follow-up questions, the program improves in accuracy and contextual awareness over time.

From a technical perspective, TheraBee is designed to handle unconventional inputs through thorough testing, scale efficiently to manage large amounts of data, and protect sensitive information with secure data storage and handling. The user interface is created to be simple and inclusive, providing customized, evidence-based recommendations in formats that are easy to understand and apply.

Through comprehensive testing, using metrics such as training loss and validation loss, as well as scenario testing, the project aims to demonstrate feasibility of detecting signs of mental health conditions, with potential to improve early screening accuracy, and broaden access to quality mental health screening. Ultimately, this solution advances the vision of using artificial intelligence responsibly to improve mental health management, encouraging forward-thinking and ongoing engagement while upholding high therapeutic, clinical, and regulatory standards.

[1](Prompt Engineering: The process of designing instructions to elicit certain responses or style of response from an LLM)
[2](Hyperparameter: Parameters like temperature and learning rate that are set before training and impact both inference and learning)
[3](Autoregressively: Continually adding responses into the model's context window as the conversation progresses)

**ShotOpt: Multimodal AI-IMU-Physics Framework for Basketball Shooting Analysis and Optimization**

Xiru Zhong

Many basketball beginners struggle with making consistent shots because they do not know which adjustments in their techniques will affect shooting accuracy the most. While physics-based models can estimate optimal release conditions, they often treat all variables equally and do not account for individual differences in shooting mechanics.

This project develops a data-driven approach to personalized shooting optimization by combining video analysis, IMU sensor data, and machine learning (ML). For each user, 50-100 shots are collected using synchronized video and wearable sensors. From these data, a set of interpretable biomechanical features is extracted, including release angle, release height, joint angles, motion smoothness, and timing.

A ML model is then used to analyze which features have the strongest impact on shot success. Instead of treating all variables equally, the system weighs each feature differently and focuses on providing optimizing suggestions based on the specific weight. These key variables are then adjusted within a physics-based trajectory model to generate feasible and personalized feedback.

Evaluation results show that this optimization approach based on features' weights leads to more consistent shooting patterns and improved shot probability compared to treating all variables equally.

Key words: Machine Learning, Feature Importance, Optimization, Multimodal Analysis, Wearable Sensors

**AQD - Apple Quality Detector**

Evgeny Zatsepin

Every year, farms lose thousands of tons of fruits for a simple reason — spoilage. All the fruits eventually rot and by the time someone sees a rotten apple, it has already been rotten for days and most likely started spreading the spoilage.
That made me think: what if you could detect spoilage wirelessly sitting at your house and early enough so it wouldn't infect its neighbors?
To solve this, I built the AQD - Apple Quality Detector. It's a low-cost system that uses gas and humidity sensors to track changes in fruit as it starts to decay. Two microcontrollers communicate through long-range LoRa antennas, sending data wirelessly to an app in real time, so you can alarm the farmer on time to check the storage.
I tested the system on apples over several weeks, analyzing how conditions change during spoilage. The results were surprising - the sensors detected early signs of decay days before any visible changes appeared.
The goal is simple: catch the problem early. If farmers can identify one bad apple in time, they can prevent it from affecting the rest. Designed to be affordable and easy to use, AQD could help small farms reduce waste and better protect their harvest with minimum effort.

## JBR-15-CS

**Cyber Labs**
Theo Moua

The project is an AI that is supposed to perform labs at a set level from beginner-master which is supposed to promote teaching of technology and help companies not waste money on training programs along with being more efficent training their employees.

Noble And Greenough School

**Low-Cost Robotic Arms Cooperative Knot Tying Using Whole-Arm Manipulation**

Anray Sheng

Independent manipulation of deformable linear objects, such as ropes, remains a significant challenge in robotics due to the complexity of predicting the behavior of flexible materials. This project investigated whether two low-cost consumer robotic arms could autonomously tie an overhand knot using only onboard RGB cameras and no external sensors. It was hypothesized that by splitting the knot-tying task into independent, visually guided phases and coordinating the arms via a centralized TCP controller, an overhand knot could be reliably achieved without human intervention. The setup utilized two 5-DOF Hiwonder ArmPi Ultra robotic arms positioned perpendicular to each other, each running ROS 2 Humble on a Raspberry Pi. Blue tape markers on the rope ends were detected using HSV color segmentation, allowing each arm to localize its target and estimate the coordinates relative to its base. A TCP socket-based coordinator executed a multi-phase sequence: both arms grasped the rope ends; the second arm executed a pre-planned draping trajectory to lay the rope across the first arm's gripper to form a loop; the loop aperture was detected using convex hull analysis; and the second arm threaded the loop. In 20 independent trials with randomized rope placement, the system achieved a 95% success rate in Arm 1 initial grasping, 85% in Arm 2 initial grasping, 95% in loop formation (draping), and an 80% success rate in the final visual-servoing threading phase, resulting in a 75% overall knot-tying success rate.

**TinyML-Based Sensor Fusion for Anomaly Detection in a Model Jet Turbine System**

Anish Bokil

As aerospace and autonomous systems increasingly depend on onboard decision-making, real-time detection of mechanical faults without reliance on cloud computing has become a critical challenge. Traditional condition monitoring methods rely on scheduled inspections or remote processing, limiting their ability to detect rapid degradation in high-speed rotating machinery. This research presents an edge-deployable anomaly detection framework that monitors turbine health through multimodal sensor fusion of high-frequency acoustic emissions and tri-axial vibration data collected from a custom-built 3D-printed model jet turbine testbed. Sensor data was processed locally using a lightweight 1D Convolutional Neural Network (1D-CNN) optimized through 8-bit post-training quantization, enabling deterministic inference within a 45 KB memory footprint on a device constrained to 256 KB RAM — a 12.5x latency improvement over cloud-based approaches. To improve robustness against previously unseen failure conditions, a K-Means clustering algorithm was integrated to establish a spatial baseline of nominal operation for out-of-distribution anomaly detection. Fault states were induced through controlled mechanical simulation: shaft imbalance via asymmetric contact pressure on the rotating shaft, and bearing friction via periodic voltage fluctuations to the motor controller, replicating irregular rotational loading. Experimental evaluation across 10 independent hardware-in-the-loop trials demonstrated a mean weighted F1-score of 0.91, with per-class scores ranging from 0.91–0.96. The K-Means layer successfully flagged an out-of-distribution fault condition absent from training data in all trials. This work validates a scalable TinyML-based framework for real-time Condition-Based Maintenance, directly addressing the latency and connectivity constraints that make cloud-dependent diagnostics infeasible for autonomous aerospace and UAV platforms operating in signal-denied environments.

Keywords: TinyML, sensor fusion, anomaly detection, convolutional neural network, edge computing, condition-based maintenance, 8-bit quantization, K-Means clustering, mathematics, structural health monitoring, embedded systems, predictive maintenance, aerospace, UAV

**Predictive Modeling for Prime Investment Decisions**

Madhavi Chalivendra

Utilizing the yfinance module in Python to predict the close value of the company name entered by the user. In order to do this, LSTM - an advanced regression model - is used.

**From Novice to Investor: A Learning App for Stock Market Fundamentals**

Neya Maharjan, Kenton Tran, Noel Lopez

The surge in day☐trading over the past decade has led to a rise in new brokerage accounts, yet most retail investors consistently underperform and lose money. Existing trading platforms and educational tools often encourage impulsive behavior, lack clear explanations, and overwhelm beginners, leaving them without the structure needed to build effective strategies. Surveys show major gaps in financial literacy, with many new traders feeling unsure about real trading strategies and overwhelmed by market complexity. Key factors driving widespread losses include financial illiteracy, emotional decision☐making, and poor discipline, which trap beginners in a cycle of repeated mistakes. A successful solution must not only teach fundamental concepts but also help traders regulate emotions, think rationally, and follow structured processes, addressing shortcomings that past stock indicators have failed to solve. For this solution, we've each individually and collaboratively brainstormed ideas, coming up with the best products possible. Through this brainstorming, we have come up with WeGoUp, a stock indicator that aids users and provides easy-to-learn lessons to engage and educate them to the fullest extent. When testing, we made sure that our indicators' buttons functioned, the lessons were easily understandable, and that the market information provided on our site was accurate and actively updating.

**Screen Time's Impact on the Adolescent Brain**

Ateeq Rahman, Ritchy Samedy

Excessive smartphone usage is linked to significant mental health concerns among adolescents, with those spending 4+ hours daily on screens showing 27% higher anxiety and 26% higher depression rates. Current screen time apps fail because they operate in isolation, relying solely on individual willpower without external accountability. This project solves this by developing an app that integrates social accountability features with traditional screen time tracking. The prototype will allow users to share their screen time data with friends, promoting peer-based motivation to reduce excessive screen time. Survey data from 105 responses shows 82.1% would be more motivated to minimize screen time if friends could see their usage patterns. The application will be developed using Flutter/React for the frontend and tested with a focus group to validate its effectiveness in promoting healthier smartphone habits through social transparency and accountability.

**Predicting Mutated Genes in Multiple Myeloma from Blood-Smear Whole-Slide Images: An Early Exploration Model**

Afya Shaikh

Identification of multiple myeloma on blood-smear or bone-marrow whole-slide images (WSIs) is time-consuming and subjective in early diagnosis. This study will assess whether a small convolutional segmentation technique is capable of predicting myeloma-rich areas on WSIs. WSIs were tiled into 512×512-pixel patches and split 80/20 into training and validation sets (batch size 2). Light U-Net–variant convolutional neural network performed binary segmentation (background/myeloma) and was optimized with Adam (learning rate 5×10☐☐) using composite loss of class-weighted cross-entropy and Tversky (α=0.8, β=0.2). Accuracy was evaluated by precision, recall, F1 score, accuracy, area under the receiver operating characteristic curve (AUC ROC), and confusion matrix. Accuracy in validation data was 0.79, and the AUC was 0.92. Whole results were: background—precision 1.00, recall 0.78, F1 0.88; myeloma—precision 0.18, recall 0.98, F1 0.30, which shows high sensitivity but many false positives under extreme pixel-level imbalance. This model is useful to pathologists because it can indicate suspicious regions and help reduce time and errors. It can be improved with rebalancing and enhancing the data, tweaking thresholds and training parameters, trying stronger encoder backbones, training longer, and validating on a patient level so that it can generalize to new cases.

Key words: Cancer, machine-learning, technology, myeloma, image detection

Billerica Memorial High School

**TEMPO: A Novel Hybrid Neuromorphic Framework for Efficient and Interpretable Integration of Multi-Omic High-Dimensional Oncology Data**

Lucia Nanda

Efficient multi-omic data fusion is essential for precision oncology, from real-time tumor monitoring to assisted diagnosis. Conventional deep learning (ANN) models tend to achieve the highest performance with multi-omics data but struggle with efficiency, interpretability, and overfitting in high-dimensional environments. Spiking neural networks (SNNs) offer a biologically-inspired alternative with superior energy efficiency, but are not well-suited for dense, multi-omic data and generally produce lower performance. ANN-SNN hybrids have been explored but often suffer from compatibility issues. This project introduces TEMPO (TEmporal Multi-omic Platform for Oncology), a multi-omic framework for ANN-SNN hybrids. Unlike traditional hybrids, TEMPO is built around a neuromorphic-based pipeline with the inclusion of ANN-based/advanced features, including: hybrid spike encoding, semantic addressing, differentiable categorical routing, and balanced focal learning with weighted random sampling. TEMPO was validated against ANN and SNN baselines on TCGA-GBM and TCGA-PANCAN datasets, supported by ablation studies. The TEMPO model achieved a 0.96 AUC, reducing computational operations by 33.8% and factored energy costs by 41.2% compared to ANN baselines, with a less than 5% trade-off in raw accuracy. In addition, TEMPO's semantic addressing and selective routing enabled the complete mapping of feature prioritization and led to interesting discoveries such as the potential connection between COX15 and Melanoma and RIF1 as a pan-subtype discriminator across multiple cancers. These results demonstrate TEMPO's potential to substantially promote efficiency with a modest performance tradeoff. Future research would emphasize the refinement of TEMPO features, dual chip deployment, and implementation in low-resource oncology settings and energy-intensive medical applications.

**NeuroFusion: An Novel Integrated Model Fusion Framework for Robust Cross-Pathology Classification**

Advaith Vijayasankaran

Deep learning shows promise in MRI-based diagnostics, but remains limited by issues with reliability, interpretability, and computational efficiency. This is because monolithic architectures fail to capture feature representations across imaging planes. I hypothesized that an intermediate multibranch fusion architecture could address these limitations by jointly learning shared representations. In this study, I introduced NeuroFusion, a novel deep learning architecture that employs intermediate multibranch feature fusion to enhance diagnostic performance. NeuroFusion was evaluated against baseline CNNs and ensemble methods using 5-fold cross-validation across five conditions: Parkinson’s disease, Alzheimer’s disease, Multiple Sclerosis, Stroke, and Brain Tumors. NeuroFusion achieved an average accuracy of 92.76%, significantly outperforming baseline (71.58%) and ensemble (82.27%) models. This performance increase was also statistically significant ($p < 0.0003$). By integrating bi-planar views, the model reduced False Negatives by 18%. Pareto front analysis confirmed it as the sole non-dominated solution, delivering a 3.2ms/scan inference speed, which is 2x faster than ensembles despite a 40% parameter reduction. Additionally, Grad-CAM visualizations confirmed that NeuroFusion focused on clinically relevant regions, including cortical atrophy and ischemic lesions, validating the interpretability of its predictions. NeuroFusion also stayed consistent under Gaussian noise testing, outperforming existing models at the $\sigma = 0.15$ threshold. My findings suggest that intermediate feature fusion not only improves model robustness but also provides an optimized framework for AI-assisted diagnostic decision support in clinical neuroimaging. Future work will explore the integration of multi-modal data with the potential to accelerate early diagnosis and treatment of neurological disorders.

**Analyzing Packet Transmissions In Low Power Wide Access Networks to identify zero-day Denial-of-Service Attacks using Zero-Shot Techniques**

Kaushik Satheesh Kumar

LPWAN networks enable cost-effective, low-power, long-range communications between a larger number of IoT devices on a single network and are projected to grow at a rate of 26% by 2027. However, their lightweight protocol makes them vulnerable to Denial-of-Service (DoS) attacks, which inflict serious damage by taking down the network. Existing intrusion detection systems (IDS), while effective at preventing well-documented attacks, completely fail against zero-day attacks. This research aims to develop a Generalized Zero-Shot Learning (GZSL) model that can proactively detect zero-day DoS attacks at the OSI Layer 4 by analyzing packet transmissions. Three models—a control model, a non-generative GZSL model, and a generative GZSL model were trained and evaluated. For the GZSL models, seven descriptions were defined per attack, with normal and flooding attacks treated as seen classes and energy drain and replay attacks treated as unseen classes. The performance metrics—seen accuracy, unseen accuracy, harmonic mean, precision, recall, F1 score, and training time—were recorded over 10 trials. The generative GZSL model achieved a higher harmonic mean (0.383) compared to the control (0.000) and non-generative GZSL model (0.217) ($p < .001$, $\eta^2 = .98$, $F = 6.34$). The control model produced a higher F1 score than both GZSL models, but not statistically significant ($p = 0.991$). This model was also condensed and deployed on a Raspberry Pi gateway with an integrated LIME-Qwen explainability pipeline and achieved sub-100 ms latency. Therefore, when deployed at the gateway, the GZSL model can proactively detect malicious packets to mitigate zero-day DoS attacks.

Bedford High

**Audio Augmented Reality for the Night Sky: A Music-theoretic and Spatial Sonification Approach**

Hanna Suzuki

This project studies audio augmentation in augmented reality (AR) by developing a spatial sonification method rooted in music theory. Although AR technologies are increasingly prevalent in education and entertainment, most existing AR research and applications rely almost exclusively on visual augmentation, with limited use of meaningful audio. Focusing on astronomy as a gateway to STEM learning, this project addresses the gap by augmenting celestial objects (e.g., constellations) with musical representations sonified directly from their astronomical features (e.g., position on the celestial sphere, area/size, brightness, and local deep-sky features).

By translating astronomical data into musically coherent compositions based on established music-theoretic principles (e.g., chord progression guided by functional harmony, melodic cadences, and voice-leading constraints), the proposed sonification method allows learners to perceive and explore celestial objects through auditory modalities. The accompanying AR device extends this experience beyond the classroom by supporting immersive interaction with celestial objects under the night sky through a virtual spatial soundscape. The device performs realtime object identification and audio-guided search by rendering three-dimensional sounds that appear to originate from specific celestial objects.

A structured user study of over 90 participants shows that the proposed method is effective even for novices, with consistently high accuracy across recognition tasks in identifying and distinguishing constellations from musical representations (90–96%). Participants also exhibit substantial learning gains, including a 65-percentage-point increase in their ability to associate constellations with their musical representations, and report strong engagement and educational value. These results demonstrate the method’s effectiveness as a multimodal learning approach for astronomy.

**Fusion-Based Driver State Monitoring: A Multimodal Approach to Drowsiness Mitigation**

Suhrit Ghosh

Driver fatigue is a major cause of vehicular accidents despite existing single-module detection methods. This study developed and validated a multimodal driver fatigue intervention system that integrated sensor inputs and machine learning to provide accurate real-time detection and mitigation of driver drowsiness. The hybrid system analyzed data from three modules: a computer vision module using convolutional neural network machine learning-based object detection to detect behavioural fatigue, an array of force-sensing resistors (FSRs) to monitor postural shifts, and an accelerometer to detect irregular head movement. Data fusion was achieved through a programmed algorithm to identify individual-specific patterns of drowsiness. The integrated system achieved 97% accuracy in classifying drowsy states, with the alert system activation having a mean latency of 0.47 seconds after detection. These results demonstrated that the fusion of behavioral, positional, and kinematic data offered a significant improvement in reliability over existing single-module or vehicle-based methods. By assessing the driver's physical state before hazardous driving performance occurred, this system provided a robust solution for early intervention to effectively reduce traffic-related fatalities.

Keywords: drowsiness, multimodal, sensor fusion, machine learning, convolutional neural network (CNN), computer vision, force-sensing resistor (FSR), accelerometer.

**Multi-Agent UAV Swarm Real-Time Safe Passage Mapping System for Fire Rescue**

Zuming Zhang

Key words: Multi-Agent UAV Swarm; Fire Rescue; Dynamic Path Planning; 3D Reconstruction; Safe Passage Mapping; Leader-Follower Architecture; Edge Computing

This research proposes a Multi-Agent UAV Swarm Real-Time Safe Passage Mapping System for Fire Rescue to enhance the efficiency and safety of fire rescue operations. Traditional methods often suffer from delayed information and insufficient situational awareness, leading to prolonged rescue times and increased casualties. Our system addresses this by deploying a multi-agent UAV system with a Leader-Follower architecture. The Leader UAV identifies macro fire locations and guides Follower UAVs, which collect micro-level data using a lightweight chain-of-thought mechanism. This data is then used to generate and dynamically update a 3D safe passage map, identifying the shortest safe paths from fire sites to exits within seconds. Through rigorous experimentation in visually simulated fire environments, encompassing scenario setup, UAV deployment, communication network establishment, edge-side processing for dense 3D reconstruction, and dynamic path planning, we aim to validate the system's ability to significantly shorten rescue times and reduce operational risks for ground teams. Key performance indicators will include safe passage generation time, path accuracy, and UAV task completion rate, with results compared against traditional rescue methods to demonstrate enhanced rescue efficiency and safety.

Andover High

**AI-Based Early Detection of Cognitive Decline in Cancer Patients Using the MIMIC-IV Dataset**

Diya Nainwal

Cancer-related cognitive decline (CRCD) is a clinically significant yet under-studied complication of cancer and its treatment, with consequences for treatment adherence, quality of life, and caregiver burden. As cancer survival rates improve, there is a growing need for scalable methods to identify patients at risk for cognitive impairment using routinely collected clinical data. This study investigates whether patterns in structured and unstructured electronic health record (EHR) data can predict cognitive decline in patients with cancer.

We conducted a retrospective analysis using the MIMIC-IV database, a large, de-identified critical care EHR dataset containing longitudinal structured data and unstructured clinical notes. Cancer patients were identified using ICD-9 and ICD-10 diagnosis codes, and cognitive decline was labeled using a hybrid approach combining cognitive-related diagnosis codes with NLP-extracted symptom mentions from clinical notes. Structured variables and NLP-derived text features were used to train and compare multiple machine learning models, including logistic regression, k-nearest neighbors, and neural networks.

Results indicate that cognitive decline occurs more frequently among cancer patients than non-cancer patients and is often documented in clinical notes even when not formally coded. Models incorporating unstructured text features demonstrated improved predictive performance over structured-only approaches, while interpretable models highlighted key demographic, clinical, and linguistic indicators associated with cognitive decline.

These findings demonstrate the value of integrating NLP with EHR data to improve detection of cancer-related cognitive decline. Earlier identification may support increased clinical awareness, more proactive supportive care, and better preparation for patients and families. Future work should explore longitudinal modeling and external validation across healthcare systems.

**A Severity-Aware Reinforcement Learning System for Optimizing Abdominal Hemorrhage Resuscitation in Physiological Simulation**

Michelle Xu

Hemorrhage is the leading cause of preventable death after trauma, accounting for 30-40% of deaths following events such as motor vehicle accidents. Proper early resuscitation is crucial, yet ideal strategies are debated, and treatment errors are extremely common. Reinforcement learning (RL) is a natural framework for such problems involving sequential decision-making, however existing medical RL approaches rely on narrow, biased clinical datasets or reduce the problem to single-variable control using oversimplified models. This research aims to develop a decision-support system that optimizes hemodynamic and hemostatic resuscitation after traumatic abdominal hemorrhage during the pre-operative period without requiring vast clinical data. With optimal strategies differing drastically by hemorrhage severity, this project developed the first Mixture-of-Experts medical RL system for severity-stratification. Two specialized RL agents were trained through interaction with a high-fidelity physiological simulator enhanced with custom coagulation modeling, eliminating reliance on clinical data. The agents learned distinct strategies for high and low-severity hemorrhage, with a recurrent policy enabling temporal reasoning in severe cases. Evaluated on 50 diverse test episodes, the system stabilized 81.9% of patients, achieving 36.3% higher stabilization than a single-policy controller (45.6%) while using 77% less blood. The severity-aware system maintained target perfusion pressures 94% of treatment time compared to only 71% for the single-policy prototype. Learned strategies aligned with clinically validated protocols, demonstrating that severity-stratified RL can safely discover hemorrhage treatment policies without clinical data, establishing a framework applicable to other medical domains where data is scarce or strategies are debated and difficult to execute.

Keywords: reinforcement learning, Mixture-of-Experts, hemorrhage resuscitation, multi-agent systems, computational physiology, trauma resuscitation, clinical decision support

**Vision-Language Object Detection for Drone-Based Natural Disaster Monitoring and Damage Assessment**

Kathy Lin

After natural disasters such as earthquakes, floods, or wildfires, rapid situational awareness is critical for saving lives. Drones are increasingly used for disaster monitoring, but most existing drone vision systems rely on human operators or basic classification, slowing down their operational efficiency. This severely limits their usefulness in real-world disaster scenarios. Recent vision language object detection models allow detection of objects described by a text prompt, which is useful for disaster monitoring with complex scenarios. This project features an end-to-end search and rescue drone system using natural language prompts to detect rescue targets, hazardous objects and analyze natural disaster scenarios to provide information to first responders.

The system hardware is a custom drone using an open-source Pixhawk flight controller. The drone is equipped with a Raspberry Pi to perform real-time detection at the edge. The key feature of the machine learning system is an edge-to-cloud detection pipeline, with two-phase detection for accuracy and efficiency. YOLOE-based vision language object detection is used at the edge, and Channel Wise Knowledge Distillation (CWD) is used to increase the accuracy of the model while minimizing the computation for real-time detection. The edge-to-cloud pipeline uses both entropy-based uncertainty and epistemic uncertainty to determine which images must be analyzed again with the Large Vision Language Model (LVLM) after being sent to the server. This system balances real-time speed with deep cloud reasoning, delivering critical intelligence to first responders while optimizing bandwidth in disaster zones.

**Galaxy Classification Based on Machine Learning**

Ian Kim

We present a machine-learning approach for automated galaxy classification based on morphological features such as shape and structure. Accurate classification supports aerospace and astrophysical research by revealing relationships between galaxy types and large-scale phenomena, and by helping optimize scientific instruments. As space missions generate images of millions of galaxies, manual labeling becomes impractical, making deep learning essential for efficient analysis.

As a result, we evaluate machine-learning techniques for galaxy classification and propose using an ensemble of models to improve performance beyond that of any individual approach. We also suggest enhancing image resolution to further increase accuracy. These strategies together can significantly advance automated galaxy classification for modern astronomical research.

Pioneer Charter School of Science

**A Smart Microcontroller-Based Visual and Light Feedback System Using ESP32-CAM and OLED Technology**

Mannat Markan

Color blindness affects millions of people worldwide and makes everyday tasks such as identifying colors in clothing, crayons, and paint difficult. Commercial color-reading devices are available but are often expensive and inaccessible to many users. This project will focus on the design and development of a low-cost, portable color reader using an ESP32-CAM microcontroller. The system uses the built-in camera to capture images of objects and analyze their color, then communicates the detected color by a visual display. Open-source hardware was used to keep the total cost under $30. Testing showed that the device was able to correctly identify 92% of the time. The results showed that an affordable microcontroller-based system can be used to create effective assistive technology.

**Uncertainty□Aware Adaptive Huber□Loss Federated Distillation for Thermal Anomaly Detection in UAV Networks**

Jinwoo Park

Thermal anomaly detection from unmanned aerial vehicles (UAVs) is increasingly used for applications such as early wildfire discovery, post-disaster monitoring, and infrastructure inspection. In practice, UAV fleets operate in highly heterogeneous environments and acquire thermal imagery of variable quality due to motion blur, sensor drift, altitude changes, and reflections. These factors yield strongly non-IID client data and heavy-tailed prediction residuals that can destabilize collaborative learning. To address these challenges under bandwidth constraints, we propose an uncertainty-aware federated distillation (FD) framework that exchanges compact logits rather than full model parameters. The framework targets binary anomaly detection and naturally extends to multi-task thermal characterization (e.g., anomaly size and growth severity) via additional heads. Our approach introduces (i) a client-adaptive Huber threshold that is learned locally to robustify distillation against outlier residuals, and (ii) heteroscedastic uncertainty weighting that downweights ambiguous or corrupted thermal frames during local optimization. We provide an end-to-end training protocol for UAV networks and evaluate it using non-IID simulations as well as a real-world UAV case study pipeline based on a DJI Mavic platform paired with a lightweight thermal sensing payload. Finally, we perform ablation studies to isolate the contributions of adaptive robustness and uncertainty weighting under connectivity and distribution shift.

Index Terms—UAV networks, thermal anomaly detection, federated learning, federated distillation, robust loss, Huber loss, uncertainty modeling, non-IID learning.

**A Unified Protein Embedding Model with Local and Global Structural Sensitivity**
Jerry Xu

Structural comparison between proteins is key to many research tasks, including evolutionary analysis, peptidomimetics, and functional annotation. Sequence alignment algorithms are ineffective, since many structural homologs differ significantly in sequence. While superposition-based structural alignment tools are accurate, they are computationally expensive and impractical at scale. Furthermore, such algorithms are usually focused on either global or local structural similarity, despite both being relevant in homology and protein function. In this paper, we propose a novel protein language model consisting of a transformer-based Siamese neural network, enabling efficient embedding-based structural comparison while also capturing both global and local structural similarity. Our model was trained on a dual loss function combining TM-score, a global similarity metric, and a variation of lDDT scores, a per-residue similarity metric. Our model was tested against two datasets: one consisting of diverse TM-score pairs, and one consisting of wild-type and point mutant pairs. Against these sets, our model achieved a TM-score MAE of 0.0741 and 0.0750, respectively, and a lDDT-score MAE of 0.0788 and 0.0031, respectively. Our model fulfills two key roles: first, it rapidly detects global structural differences. Second, it supports fine-grained structural assessments, improving sensitivity to subtle but functionally important structural changes.

Index Terms - Siamese Neural Network, TM-score, lDDT scores, TM-Align, TM-Vec, ProtTrans

**American Sign Language Detection Using Machine Learning Algorithms**

Leomar Ortiz Rincon, Nirvaan Shrestha

American Sign Language is thes most commonly used sign language in the United States, used by over half a million people. On a wider scope, a total of about 2.8% of all adults in the United States reported using any sign language. This ultimately results in many people who are not able to communicate with family members, as they are not fluent or knowledgeable in ASL. Thus, the hypothesis is: if a machine learning algorithm is trained on a large and diverse data set of American Sign Language gestures, then it will translate ASL into English with relative accuracy. Our project uses several AI models and tools in order to train a model that is able to classify static signs (mostly the ASL manual alphabet) so as to translate a string of signs into characters, and then from characters to correct English. Our approach was to use the Python library OpenCV to allow for usage of the camera and annotate images, Google AI Edge's Mediapipe models to extract hand landmarking data, the collection of algorithms provided by the library scikit-learn to train the model, and the Google Gemini 3 Flash Preview model for parsing the string of letters into proper English. We were able to train a model by having subjects hold their hands up while signing and capturing the landmarks. In the end, a model is able to be trained that can detect static signs with relative accuracy.

**The Breaking Point: A Holistic Approach to Forecasting Socio-Economic Distress and Structural Breaks Under Persistent High Inflation Using a Novel Time-Aware Transformer Framework**

William Guo

Persistent high inflation has caused widespread socioeconomic distress, including rising poverty, higher crime rates, widening income inequality, greater unemployment risk, reduced educational attainment, declining access to healthcare, and escalating cost of living burdens. These effects disproportionately harm low-income households and vulnerable communities. This underscores the urgent need for a more accurate understanding of how inflation propagates through socio-economic systems and how its impact can be forecasted proactively rather than observed retroactively.

This research advances socio-economic distress forecasting through a new holistic and systematic approach, making the following contributions:

• The development of a novel time-aware Transformer-based approach that systematically and accurately predicts and quantifies the directional impacts on socio-economic distress indicators based on inflation and macroeconomic inputs.

• The identification of latent “breaking points” where inflationary pressures lead to structural breaks in socio-economic stability, offering policymakers valuable insights for proactive resource allocation.

• The discovery of long-range dynamic causal relationships between inflation, social distress, and structural breaks in socio-economic stability.

• The detection of dependency patterns previously unrecognized by conventional econometric tools and traditional linear and machine learning approaches.

• The systematic investigation, identification, and quantification of the most important socio-economic distress indicators and the creation of the world's first comprehensive and unified database of these indicators.

• The generation of actionable insights for policymakers, enabling proactive resource allocation to communities most at risk of inflation-driven instability, and offering an early warning system for socio-economic stress.

Keywords:
Inflation impact, socio-economic distress indicators, Transformer, poverty, crime, income inequality, structural breaks, computational social economic science, cost of living.

Andover High

**Learning Disturbance Models to Improve Precision in Autonomous Control Systems**

Pranav Polisetti

Classical Proportional-Integral-Derivative (PID) controllers are widely used in autonomous aerial vehicles but degrade in performance when introduced to external disturbances not properly accounted for in the mathematical model. This study investigates whether a neural network trained to estimate disturbance dynamics can augment a PID controller and improve trajectory tracking in a simulated planar quadcopter. A dataset was generated by running the PID controller under a range of random disturbances, and then a feedforward neural network was trained to predict the applied horizontal and vertical disturbance forces from the quadcopter's instantaneous state. The resulting hybrid controller blended PID outputs with compensated disturbance by using a time-ramped influence factor. Performance was evaluated at disturbance magnitudes (dx, dz) of (0, 0), (1, 1), (2, 2), and (5, 5) using mean squared error (MSE) and overshoot as metrics. At the highest disturbance level tested, the PID-only controller resulted in an MSE(x) of 816.2 and an overshoot of 63.05, whereas the hybrid controller achieved an MSE(x) of 1.282 and an overshoot of 2.107. These results indicate that neural network-based disturbance compensation significantly improves the robustness of model-based controllers when there are external forces, while maintaining baseline stability.

Lexington High

## Pathway-Level Machine Learning Analysis of Breast Cancer Gene Expression Data for siRNA Target Prioritization

Austin Li

Large-scale cancer transcriptomic datasets provide critical insight into tumor biology; however, translating these data into therapeutically actionable targets remains a major challenge. This study investigated whether pathway-level modeling of gene expression could enable accurate tumor classification, survival risk prediction, and prioritization of small interfering RNA (siRNA) targets—short RNA molecules that silence specific genes by degrading messenger RNA—in breast cancer. RNA sequencing data from the TCGA Breast Invasive Carcinoma cohort were summarized into pathway activity scores and analyzed using regularized classification and survival models. Pathway-level features alone distinguished tumor from normal tissue with near-perfect performance (AUROC = 0.998; average precision = 1.000) and produced a strong separation between high-risk and low-risk patients (log-rank $p < 1 \times 10^{\square 1 \square}$). High-risk tumors were enriched in pathways associated with key cancer hallmarks, including sustained proliferative signaling, resistance to cell death, and evasion of growth suppressors. Integrating classification importance, survival contribution, and RNA interference feasibility reduced thousands of genes to a small set of high-confidence candidates. Notably, MAPK1, PPP2CA, FGF9, and MAP2K1 demonstrated strong biological relevance and a high number of sequence-feasible siRNA designs. These findings highlight the value of pathway-level modeling as a scalable framework for linking transcriptomic data to functional therapeutic strategies and advancing rational siRNA target discovery in cancer.

Keywords: breast cancer, TCGA, transcriptomics, pathway analysis, GSVA, machine learning, survival analysis, siRNA, RNA interference, target prioritization

Cambridge Rindge and Latin

**Early Fault-Tolerant Quantum Algorithms for Predicting Market Crashes**

Shreyan Mazumder

Financial markets exhibit non-linear dynamics invisible to classical models — the 2008 crisis erased $10T with no warning. This project builds a complete quantum TDA pipeline: Takens delay embedding, corrected QPE, Pauli Channel Encoding, and Variational Phase Estimation, validated on IBM ibm_torino. VPE achieved 11.9× circuit depth reduction vs. QPE with 100% accuracy. IBM hardware returned β☐=0.99 (truth=1, TVD=0.1403). The pipeline flagged 32/89 anomaly windows on synthetic S&P 500 data, with β☐ spikes ~20 days before each crash window.

**ENDO-EC: An Automated Early Esophageal Cancer Detection System via Image Classification and Lesion Segmentation**

Neha Nagireddy

Esophageal cancer, affecting approximately 511,054 people globally in 2022 and causing 445,391 deaths, is a highly aggressive malignancy with a five-year survival rate of only 22.9% due largely to late-stage detection. Despite advances in endoscopic imaging, early esophageal cancer (EEC) is frequently underdiagnosed because early lesions are subtle and often asymptomatic. Studies show that 22–25% of EEC lesions were missed during prior upper endoscopy, with diagnoses occurring months later at more advanced stages. Access to specialists further compounds this issue, as 69.3% of U.S. counties and 87.4% of rural counties lack a gastroenterologist, limiting timely diagnosis. ENDO-EC aims to address these gaps by using deep learning and computer vision to improve early detection through automated image classification and lesion segmentation of endoscopic images. A CNN first classifies images as cancerous or non-cancerous, and an Attention-enhanced U-Net then delineates suspicious lesions when present. By combining accurate classification with precise segmentation, ENDO-EC offers a scalable, computationally inexpensive solution to significantly reduce missed lesions and support earlier diagnosis, particularly in rural and underserved populations.

**Repurposing FDA Approved Drugs to Fight Neglected Tropical Diseases Using Deep Learning**

Daniel Korkin

Neglected tropical diseases (NTDs) disproportionately affect populations in low-income regions, where low funding and infrastructure have limited traditional drug discovery efforts and slowed the development of effective treatments. Recent advances in artificial intelligence (AI) and deep learning offer a scalable and cost efficient alternative for accelerating drug discovery and repurposing. Modern deep learning architectures, including transformer models and graph neural networks (GNNs), enable accurate modeling of protein structures and prediction of protein-ligand interactions at unprecedented scale. In this project, I developed a deep learning based, high throughput computational pipeline to identify FDA approved drugs that can be repurposed to target proteins associated with a broad range of neglected tropical diseases. The pipeline builds upon a recently published GNN model for predicting protein ligand binding affinity. Because the original model was trained using protein structures generated by earlier protein modeling tools, I retrained the GNN using state-of-the-art protein structures predicted by AlphaFold 3. This retraining resulted in improved binding-affinity prediction performance compared to the original model.

Using the optimized pipeline, I conducted a large-scale virtual screening of approximately 450 druggable NTD related proteins curated from the TDR Targets database against approximately 2,900 FDA approved drugs obtained from DrugBank. Three dimensional protein structures were generated using AlphaFold 3, yielding roughly 1.3 million protein ligand pairs. Each pair was evaluated by the trained GNN to predict binding affinity. The top 100 highest scoring protein ligand interactions were further validated by structure prediction of full protein ligand complexes using AlphaFold 3 and CHAI-1, two of the most accurate protein ligand modeling tools currently available. This work demonstrates the potential of deep learning driven drug repurposing as an economically efficient strategy for accelerating drug discovery for neglected tropical diseases. All high affinity protein-ligand predictions generated in this study will be made publicly available to the research community.

**Identifying Novel Alzheimer's Disease-Modifying Targets using Simulated Cell Output from Perturbation Experiments (SCOPE)**

Soham Samanta

Alzheimer's disease (AD) causes progressive brain degeneration and remains incurable. Growing evidence points to reactive astrocytes as active contributors to disease progression, but it is unclear which genes actually drive the reactive state versus which are simply turned on as a consequence of it. This matters because only genes that truly drive the process are useful therapeutic targets. To address this, I developed SCOPE (Simulated Cell Output from Perturbation Experiments), a computational pipeline that simulates gene deletions in over 100,000 astrocytes from postmortem AD brain tissue to identify which deletions push reactive astrocytes toward a healthier state. SCOPE found over 2,000 genes whose deletion shifted reactive astrocytes toward homeostatic identity, while housekeeping genes had no effect. I then used Cell Projected Phenotypes (CPP), a method that assigns disease scores to individual cells based on clinical data from their donors, to test whether these shifts reflect actual improvement in disease phenotype. CPP analysis separated the top SCOPE hits into two categories: genes that are associated with reactivity but whose deletion worsens disease scores, indicating they are biomarkers, and genes whose deletion genuinely improves disease scores, indicating they are potential therapeutic drivers. Through combinatorial analysis, I identified a set of driver genes whose combined deletion moves reactive astrocytes toward a less disease-associated state, several with existing drugs in development. SCOPE offers a practical way to separate true disease drivers from bystander genes in single-cell data.

Framingham High School

**Developing an Uncertainty-Aware Machine Learning Framework for Improved Ranking of AXL Kinase Inhibitors**

Amogh Singh

The identification of effective kinase inhibitors remains a major challenge in drug discovery, particularly for targets such as AXL kinase, which is involved in the progression, metastasis, and drug resistance of lung, breast, and pancreatic cancers. Experimental screening is costly and time-consuming, motivating the need for computational approaches that can prioritize promising inhibitory compounds. Most existing machine learning methods focus solely on predictive accuracy and do not incorporate uncertainty into predictions or rankings, limiting their reliability in real-world scenarios.

This project presents a machine learning framework to predict inhibitory activity against AXL kinase (pIC□□) while also generating uncertainty estimates. Two approaches were compared: a neural network trained on molecular embeddings and a Random Forest trained on molecular fingerprints. Models were evaluated using prediction accuracy metrics (MAE and RMSE) and uncertainty metrics (calibration and uncertainty-error correlation). The Random Forest was selected for further analysis due to its superior combination of accuracy and uncertainty estimates.

An XGBoost-based ranking model was then developed to integrate predicted pIC□□ values with uncertainty estimates to improve the ranking of candidate compounds. Results show that the Random Forest accurately predicts pIC□□ with well-calibrated uncertainty strongly correlated with prediction error. Incorporating these uncertainty estimates into the ranking model improved ranking metrics, such as hit rate, compared to the baseline approach based solely on predicted pIC□□.

These findings demonstrate that integrating predictive modeling, uncertainty quantification, and ranking methods offers a more robust and reliable computational strategy for virtual screening, accelerating early-stage drug discovery while improving confidence in compound prioritization.

**Reducing Recycling Contamination Through AI-Powered Waste Classification: Development of an Automated Smart Recycling System**

Anjan Bharath Reddy Lakkadi

With the global increase in waste processing, and at parallel waste contamination, waste classification has become essential to ensure processing integrity. This project investigated the optimization of a Convolutional Neural Network (CNN) based on the MobileNetV2 architecture to classify waste into 5 distinct categories: paper, metal, plastic, glass and trash. Using the TrashNet dataset (2,527 images), a 70/15/15 split was implemented to create distinct training, validation, and test sets. Together there were a total of 1638 training images, 302 validation images, and 384 test images.

This experiment was composed of 5 iterative phases, each that defined the continuous progression throughout the experiment. Phase 1 (baseline) was a simple 9 layer CNN made up of a custom architecture, which achieved an accuracy rate of 43.75%, relatively low. Phase A-D consisted of a transfer learning implementation. Phase A utilized frozen pre-trained weights, achieving 85.65% accuracy but a high loss (0.528), indicating high uncertainty. Phase B introduced increased data augmentation to improve generalization, stabilizing the model but dropping the accuracy to 84.90%. Phase C implemented fine tuning by unfreezing 20 layers off of MobileNetV2. The final iteration, Phase D, utilized a deeper fine tuning strategy, unfreezing 30 layers while simultaneously implementing an adaptive ReduceLROnPlateau scheduler. This configuration achieved the model's peak performance with a 87.50% test accuracy and 90.19% validation accuracy with a loss of 0.424. The given results demonstrate that while basic transfer learning can drastically improve a CNN from scratch, the combination of deeper layer unfreezing and a dynamic learning rate decay is critical for distinguishing between materials with similar reflective properties, like glass and plastic. Overall, this optimized model provides a robust framework for integration into real-time automated recycling hardware for future research.

**AI Trash Cleaning: Using AI and Machine Learning to Identify and Clean Up Trash from Bodies of Water**

Daivik Patel

Many rivers, lakes, and ponds are littered with debris, and cleaning that debris could involve a $700,000 interceptor that uses thousands of Watts to operate as a glorified filter. This project aims to test the feasibility of a low-cost AI-based autonomous robot that actively searches for trash. The robot was made using a Raspberry Pi processor and an AI Camera (IMX500) with a MobileNet SSD model costing under $250. A total of 56 test trials were conducted across different objects and orientations, resulting in a 100% detection accuracy at optimised orientations and a 63.8% overall accuracy. The high detection accuracy at optimised angles supported the feasibility of this technology in the real world if the AI model is further optimised and trained for a more diverse range of orientations. The model also only consumed a maximum of 27W, compared to the 23,000W of an industrial solution. The results of this study show that a low-cost AI-based solution is a viable and sustainable alternative to keep local lakes and rivers clean.

Acton-Boxborough Regional High

**Creating HASS: a Hyper Adaptive Synergistic Scaling for AI Optimizers**

Haoyang Gao , Hanwen Tang

Modern AI models are trained using optimization algorithms with fixed or manually scheduled learning rates, which often fail to adapt to changing training conditions and can lead to unstable or inefficient learning. We introduce Hyper Adaptive Synergistic Scaling (HASS), a closed-loop learning rate controller that works alongside existing optimizers by regulating how large each training update is relative to the model’s parameters using real time feedback, drawing on principles from feedback control systems. By continuously adjusting the global learning rate based on observed training dynamics, HASS aims to improve stability and efficiency across a range of models and tasks, addressing growing concerns about training cost and efficiency.

Acton-Boxborough Regional High

**High-Efficiency Geometric Adaptation (Hega): A Geometry-Aware First-Order Optimizer With Strong Nonconvex Performance**

Omar Graia

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We present HEGA, a strictly first-order optimizer that augments an AMSGrad stabilized diagonal preconditioner with two geometry signals computed along the iterate gradient path. A clipped secant based curvature estimate gives a scalar path scale and an exponentially smoothed gradient alignment score gates a convex mixture between the scalar and diagonal branches and modulates the step through the alignment score. All operations are vectorized, resulting in O(d) time and memory per step. We prove uniform bounds on the effective preconditioner, obtain $O(\sqrt{T})$ regret in online convex optimization for an anchor-metric variant that operates entirely in the AMSGrad metric, and establish local linear convergence for the main algorithm on smooth objectives with extensions under the Polyak-Lojasiewicz condition (deterministic and stochastic). Across 20 test functions (dimensions 5-10,000), HEGA achieves the top normalized overall score, outperforming the next best by 55% on the main tests (5-1,000) and 41% on the high dimensional stress tests (2,000-10,000).

Acton-Boxborough Regional High

**Deforestation Quantification in Satellite Images using Self Supervised Learning & Generative AI**

Matei Lordanescu

This project addresses the challenge of scalable deforestation monitoring by developing a multi-model fusion framework for satellite image classification combined with agentic AI–driven training. Forests play a critical role in climate change mitigation, yet traditional monitoring approaches rely on manual analysis of high-resolution imagery, limiting efficiency and scalability. To overcome this, a classification system was designed that integrates semantic features from a state-of-the-art self-supervised pretrained vision transformer (DINOv3) with complementary spatial representations from a custom-trained Diffusion U-Net model. Using 7,199 images from the NWPU-RESISC45 dataset filtered to 13 natural landscape classes, a lightweight fusion classifier was trained while keeping both base models frozen, achieving 96.26% test accuracy and slightly outperforming the DINOv3-only baseline. The framework was further applied to large real-world satellite images through patch-based inference and probability heat index mapping, enabling quantitative visualization and measurement of deforestation patterns. A custom labeled dataset of 559 satellite patches across multiple geographic locations was used to further evaluate model performance, confirming that state-of-the-art DINOv3 features consistently outperform diffusion-based embeddings as standalone inputs. Additionally, agentic AI–driven training pipelines were evaluated and shown to achieve performance competitive with the DINOv3 state-of-the-art model without human intervention. These results demonstrate that combining foundation models, generative representations, and autonomous training systems enables accurate, scalable, and low-cost deforestation monitoring, with significant implications for environmental analysis and climate change mitigation.

Keywords: agentic AI, generative AI, deforestation monitoring, satellite imagery, multi-model fusion, transfer learning, self-supervised learning, pretrained vision transformer, diffusion models, remote sensing, computer vision, climate change, land cover classification

**Transforming Language Learning: A Fun and Scalable Game-Based Platform for Students**

Krish Nath

Students at Shishu Bharati, a weekend language school, have limited time to practice a new language outside class, making consistent practice and reinforcement difficult. This project investigates whether a curriculum-aligned, game-based platform can improve engagement, support measurable learning, and scale across games and languages.

I built a web-based language learning app in Flutter that runs on laptops, tablets, and phones. The app is organized by curriculum level and currently supports Hindi and Tamil. It uses reusable game types and a Learn ☐ Play ☐ Feedback ☐ Test structure while separating the game engine from language content such as text, images, and audio. This design allows new games and languages to be added through configuration and reusable components. Iterative design changes also addressed different learner needs and accessibility: I added image and audio hints to support phoneme recognition and alphabet association, auto-play to reinforce sequence memorization, and a hard mode to challenge advanced students. Teacher feedback was also incorporated into the design process.

To evaluate adoption without collecting personal information, I used anonymous Google Analytics and Looker reports. From September 2025 to February 2026, active users increased to 432, total page events rose to 4,714, and average engagement time increased by about 10×. Multiple in-app A/B tests compared alternative learning experience designs, and the results guided improvements to the app. Preliminary pre- and post-activity results indicate improvement in student learning.

Overall, this project demonstrates a scalable, curriculum-based platform for repeatable language practice and data-driven improvement.

Milton Academy

**Prediction of Cystoid Macular Edema from Retinal Vasculitis Fluorescein Angiography Images Using Convolutional Neural Network**

Celina Wang

Cystoid macular edema (CME) is a vision-threatening complication of retinal vasculitis, a rare inflammatory disease in which large imaging datasets are difficult to obtain. Detection of CME on fluorescein angiography (FA) relies on time-consuming expert interpretation, motivating automated image-based approaches to assist clinical decision-making. Deep learning methods, particularly convolutional neural networks (CNNs), have shown strong performance in medical image analysis but are often constrained by limited labeled data in rare diseases. Transfer learning mitigates this limitation by adapting pretrained models to small, task-specific datasets. In this study, we assembled a dataset of 300 de-identified late-phase 55° FA images from 150 patients with retinal vasculitis, labeled for CME presence based on clinical assessment and standardized through macular cropping, resolution normalization, grayscale conversion, and background masking. A pretrained ResNet-based CNN was fine-tuned using 80% of the images and evaluated on a held-out 20% test set. The model achieved an accuracy of 80%, an AUROC of 0.77, and an AUPRC of 0.69, with sensitivity of 0.70, specificity of 0.85, and F1-score of 0.70. These results demonstrate the feasibility of transfer learning–based deep learning for CME detection from FA images in retinal vasculitis despite limited data, supporting further validation on larger, external cohorts.

Boston University Academy

**3D Printed Static/Dynamic Finger Fracture Fixator**

Xavier Soong

Finger fractures are common and may result in considerable disability. Some complex finger fractures, particularly with small fragments and/or open wounds, are not amenable to standard treatment with splints, casts, and conventional orthopedic hardware including wires, screws, and plates. I created 3D-printed finger fracture fixators using polylactic acid (PLA) and polyethylene terephthalate glycol (PETG), then tested both for stiffness before and after sterilization for surgical use. Before sterilization, the PLA fixator demonstrated greater flexion stiffness than standard stainless steel surgical wires, while PETG demonstrated less. Because PLA and PETG melt at high temperatures, these fixators were sterilized using hydrogen peroxide gas plasma, while the stainless steel was sterilized with a steam autoclave. After sterilization, the PLA fixator maintained flexion stiffness while PETG was significantly weakened. Both PLA and PETG demonstrated significantly less lateral stiffness than flexion stiffness, although PLA was still comparable to stainless steel. The PLA fixator was then applied to a cadaveric human hand in static (single bar) and dynamic (two cut half-bar) configurations, and demonstrated excellent radiolucency for visualization of bone alignment and healing. This novel PLA fixator is readily able to secure numerous surgical wires for fixation of complex finger fractures, maintains greater flexion stiffness and equivalent lateral stiffness compared to surgical wires even after sterilization, allows for both static and dynamic fixation, provides compact and lightweight radiolucent fixation, and is both low-cost and customizable on demand, which may benefit under-resourced areas.

KEYWORDS: 3D-printed, finger fracture, fixator

Milton Academy

**Machine Learning Powered Corneal Topographer for Disease Detection**

Alex Ning

Keratoconus is a progressive corneal ectatic disease that often begins in adolescence and can lead to severe visual impairment if not detected early. While corneal topography is the standard for diagnosis, clinical topographers are expensive, bulky, and inaccessible in many screening settings. This project presents Cornea IQ, a low-cost, portable keratoconus screening system that leverages deep learning to replace traditionally complex optical reconstruction methods. The system involves two AI models: an encoder–decoder convolutional neural network (CNN) that learns a direct inverse mapping from reflected Placido rings to corneal elevation, and a ResNet-based algorithm that extracts key features from the reconstructed maps to estimate keratoconus risk. These models were implemented on a Raspberry Pi with a 3D-printed Placido lens, and experimental results demonstrate 50% improvement corneal reconstruction and 95% accuracy keratoconus screening with significantly lower cost compared to conventional clinical devices. Limitations include reliance on anterior corneal data and the need for broader clinical validation.

Northfield Mount Hermon School

**FusionStride: A Multimodal Video and IMU Based Running Injury Risk Prediction System.**

Kian Lee, Eric Zhou

Many runners suffer injuries caused by suboptimal running form and lack access to professional coaching and feedback. This project aims to develop a cost-effective, multimodal injury-prediction system for amateur runners by integrating video-derived pose data and IMU acceleration data to provide direct, actionable coaching feedback through predictive machine learning models. Previous research has largely been limited to long-term studies that identify correlations between specific IMU or video-derived kinematic variables and injury outcomes, offering only generalized predictions of future injury likelihood. To improve predictive accuracy, this project integrates joint position data from MediaPipe Pose with acceleration data collected from four custom-built, cost-effective IMU devices across 25 runners (350 datasets). The collected data were labeled by multiple professional running coaches across four categories: overstriding, limited triple extension, trunk posture, and landing suspension. Multiple machine learning models were trained on video-only data and multimodal IMU + video data to evaluate whether multimodal sensing improves the prediction of coach-like evaluations. Results showed that while both video-only and multimodal approaches could identify running-form faults (with accuracies reaching 0.718), the multimodal models generally achieved 5-10% higher accuracy in each category. These findings demonstrate that the final system can analyze new runners and generate predicted coach-like form ratings to highlight potential technique-related injury risks.

Berkshire School

**From EEG to Spectrogram Images: Using Image Generation Models to Reconstruct Sound Stimuli from EEGs**

Junwoo Lim

I am developing a pipeline to reconstruct high-fidelity speech stimuli from noninvasive EEG using diffusion-based generative modeling. Using an open dataset collected during naturalistic listening to the first chapter of Alice's Adventures in Wonderland, I align word stimulus timing to multichannel EEG with forced-alignment TextGrids and BrainVision segment markers. For each spoken word, I extract a 1 second time-locked EEG window, apply band-pass filtering and convert the signal into log–power spectrogram tensors (electrodes × frequency × time) with fixed dimensions suitable for conditioning a neural network.

In parallel, I construct target representations of the speech stimulus by converting 1-second word clips into standardized 4096×256 log-magnitude spectrogram images. These paired EEG–audio examples are organized by subject and word to support training and evaluation.

My ongoing work trains a conditional denoising diffusion probabilistic model (DDPM) to generate clean speech spectrograms from noisy intermediate states while conditioning on the EEG tensor. I quantify reconstruction fidelity using mean square error metrics for assessment. To determine the model's robustness and generalization, I will evaluate both "known-subject" decoding (conditioning on EEG from a participant represented in training) and "unseen-subject" decoding (conditioning on EEG from a held-out participant). This project demonstrates a possible practical route toward EEG-to-speech reconstruction by combining precise stimulus alignment, standardized time–frequency representations, and modern diffusion-based generative modeling.

**EEG Headset for Clinical Language Rehabilitation: Neural Oscillations in Multi-Task Assessment of Speech Processing**

Sihui Hu

Aphasia patients often retain the intent to speak despite being unable to express it. However, traditional aphasia rehabilitation relies almost entirely on overt behavioral output and cannot objectively measure language intent in real time. These internal language processes are reflected in neural oscillatory patterns that can be detected through Electroencephalography (EEG). This study demonstrates that an affordable 16-channel EEG can reliably detect language-specific neural signatures. Through a multi-task assessment consisting of 4 different task types conducted with 13 human participants, data were collected and analyzed using Power Spectral Density (PSD) with Welch's method. Results revealed highly similar trends for covert and overt language tasks, suggesting that language intent can be monitored even without overt speech production. Distinct beta-band activity at approximately 28 Hz was also identified during language processing that was absent in motor-only controls, making the high-beta oscillation as a candidate neural marker of language intent. Additionally, cognitive load increased proportionally with task difficulty from 0.16 to 0.93, validating the device's sensitivity to cognitive load. Together, these findings indicate that a low-cost EEG may enable clinicians to adapt interventions based on objective neural data, providing an accessible foundation of data-driven rehabilitation for aphasia patients.

Keywords: Electroencephalography (EEG), Aphasia, Neural Oscillations, Language Intent, Cognitive Load.

**Testing Hand Sanitizer**

Emmett Forbes, Siddharth Parmar

It is common knowledge that hand washing and hand sanitizer are easy to use and effective at killing bacteria on your skin. Not killing the bacteria on the skin and keeping it dirty can be very harmful because if any of those bacteria get into your body they can cause illness and other health issues. With the importance of these products knowing what is the most effective is very important. In our experiment our main questions were how effective is hand sanitizer and what is the optimal ethanol percentage. To find it we first cultured two different types of bacteria in LB that are very common on surfaces and hand Staphylococcus Aureus and Pseudomonas aeruginosa. We ran 3 different but very similar trial; in our first trial we had 3 different solutions first was a control which was 200 microliters of saline, then we had a pure hand sanitizer mixture which was 200 microliters of hand sanitizer, and our last mixture was 20 microliters of saline with 200 microliters of hand sanitizer. Next we got 42 tubes of 100 microliters saline 21 for each bacteria. First we mixed each bacteria with their mixture then we moved 10 microliters of that solution into the next tube which created a concentration gradient with 7 different dilutions 10^8 down to 10^2. After mixing each tube we poured each tube into its own plate making sure to spread it evenly around the plate and placing the 42 plates into the incubator. The results of our first trial showed each solution with hand sanitizer killed 100 percent of the bacteria. In our second trial we diluted hand sanitizer with saline into 7 different concentrations of saline control, 1:1, 1:2, 1:4, 1:8, 1:16, and 1:32 each totaling to 200 microlitres of total volume. After making concretion we made 42 bacteria pellets 21 of each bacteria and then added the mixtures into them before spreading them onto agar plates. After incubating we found out that each concentration except the 1:1 dilution had significant uncountable growth. For our final test we pressed our fingers onto a Agar plate and then incubated them and then either washed our hands or put on hand sanitizer then pressed our fingers onto a different plate and incubated it. The results for this test showed the hand size killed 100 percent of the canberra on our fingers while hand washing only slightly reduces the number of bacteria. These results show that using a hand sanitizer with at least 70 percent ethanol is very effective and killing bacteria and washing your hands isn't as effective but still should be used to remove physical debris such as dirt and oil which can harbor bacteria.

North Quincy High

**Introducing ValSal: A Levonorgestrel and Estrogen Intrauterine Device (LNG-ESG-IUD) Designed to Suppress Menstruation for Female Astronauts While Aiding in Bone Mineral Density (BMD) Loss**

Maisarah Rahman

Female astronauts are in need of a long-term solution that ceases their menstruation while attenuating their bone mineral density loss, so the effects of varying geometry, hole surface area, and drug-polymer ratio on reservoirs' release rates were explored to eventually transform an intrauterine device (IUD) into a dual-drug delivery system with both levonorgestrel and estrogen. Specifically, the reservoir selected needed an hourly release rate close to 11.25 milliliters as well as roughly 15 milliliters and 7.5 milliliters under two manipulated iodine solution ratios; additionally, it must have been able to fit into an average-sized uterus, and ultimately, the estrogen-dedicated reservoir needed to release its payload at a quicker rate than the levonorgestrel-dedicated reservoir. To do so, reservoirs of different dimensions were 3D printed and filled with representatives for the drug (iodine and distilled water) and polymer (sodium alginate); reservoirs were then placed in a cornstarch-water solution while containing both constant and different drug-polymer concentrations to observe and time their release rates. The data obtained showcased that reservoirs between 7.5 to 11 centimeters tall with hole surface areas between 0.758 to 3.14 square centimeters and a ratio of 1 gram of sodium alginate to 40 milliliters of iodine to 57 milliliters of distilled water diffused iodine at an hourly rate closest to 11.25 milliliters, meaning that the two variables combined with changing the polymer-drug ratio has great potential in making an IUD that can simultaneously stop one's period and preserve her bone health in space.

Milton Academy

**An Ultra-Low-Cost Semi-Rigid Exoskeleton for Equitable Orthopaedic Rehabilitation and Walking**

Anthony Wu

This paper reports the design, fabrication, and experimental validation of a low-cost semi-rigid cable-driven knee exoskeleton intended to extend orthopedic rehabilitation access in low- and middle-income countries (LMICs), where commercially available devices priced at USD 80,000–100,000 remain prohibitively expensive. The total bill of materials is held below USD 200. The principal structural innovation is a semi-rigid chain mechanism comprising interlocking segmented links. Unlike conventional rigid exoskeletons that cannot conform to individual limb geometry, or soft exosuits that suffer from actuation force loss, the proposed mechanism transitions selectively between compliant and load-bearing states, adapting passively to each patient's anatomy. A distributed multi-point anchoring system complements this architecture by distributing contact forces across the limb without requiring a rigid frame. The device provides closed-loop torque regulation over three rehabilitation modes spanning 0° to 145° range of motion, with a minimum assistive output of 10 Nm. The prototype weighs under 2 kg and can be donned within 30 seconds. Experimental validation on a full-scale anthropomorphic mannequin demonstrated strong mechanical repeatability: inter-trial joint angle deviation remained within 1°, torque output was stable across all conditions, and the anchoring system sustained consistent limb contact throughout the complete range of motion. To provide personalized rehabilitation feedback, this project introduces a device-based LLM analysis framework integrating K-Means clustering to assess rehabilitation ratings of patients and calculating the trend analysis of users' future rehabilitation status. Besides, LLM is used to generate comprehensive personalized recommendations without relying on cloud services.
Keywords: knee exoskeleton; cable-driven actuator; semi-rigid exoskeleton; K-Means clustering;large language model;Trend calculation;closed-loop torque control;

**SpineRAI: Intelligent AI-Robotic System for Pedicle Screw Planning and Surgery**

Venkat Surya  Sai Kotur

Pedicle screw malposition remains a significant challenge in spinal fusion surgery, with reported misplacement rates of 5–20% in standard procedures and up to 30–40% in complex deformity cases. These inaccuracies often lead to suboptimal load distribution, significantly increasing the risk of Adjacent Segment Disease (ASD) and hardware failure. While existing robotic systems improve consistency, they often rely on rigid manual interfaces and lack generalizable AI models capable of adapting to the systemic biomechanical disparities found across diverse global populations. To address this critical gap in Global Health Equity, SpineRAI introduces a 3-Compute System that prioritizes demographic-specific safety and surgical justice.

The framework first utilizes a Physics Engine consisting of a 6-layer Physics-Informed Neural Network (PINN) that embeds the Navier-Cauchy equations of linear elasticity to process 3D vertebral geometries and bone stiffness data derived from 2,357 NHANES profiles. By identifying that bone mineral density and Young’s Modulus values vary drastically (ranging from 2,034.5 MPa to 24,142.0 MPa) based on racial, ethnic, and metabolic factors, the system ensures that high-risk groups—often overlooked by standardized surgical benchmarks—receive personalized, validated care. This high-fidelity stress data is then fed into an Agentic Controller powered by a multimodal MedGemma LLM agent, which translates complex biomechanical tensors into natural-language surgical plans. Finally, these plans are ported to NVIDIA Holoscan edge compute systems to drive precision surgical hardware, such as the Mazor X, via a Vision-Language-Action (VLA) interface.

Validation across diverse demographic cohorts demonstrated that SpineRAI-optimized trajectories achieved a mean peak stress reduction of 18.4%, specifically mitigating the mechanical "hot spots" that lead to hardware loosening and adjacent segment failure. SpineRAI demonstrates a paradigm shift in computational medicine by integrating social determinants of skeletal health directly into the algorithmic architecture. This ensures that spinal fusion is not only technically precise but is biomechanically optimized for the specific profile of every patient, regardless of race, gender, or background, effectively democratizing high-safety surgical outcomes.

Keywords: Pedicle Screw Surgery, Spine Fusion, ASD (Adjacent Segment Disease), Physics-Informed Neural Networks (PINNs), Multimodal Agentic AI, MedGemma LLM, Health Equity, NHANES, Biomechanical Disparities, NVIDIA Holoscan, VLA Robotics.

Phillips Academy

**Optimizing Artificial Intelligence for Accessible and Mobile Skin Cancer Prediagnosis**

Angela Jin, Bradley Yao

Timely skin cancer screening remains largely inaccessible outside specialist clinics, particularly in low-resource settings where clinical infrastructure is limited. In our study we present an on-device skin cancer triage system that integrates a two-stage AI pipeline with a custom dermoscopic imaging platform deployable on a Raspberry Pi or smartphone. The classification model combines EfficientNet-extracted visual features with attention-weighted morphological features extracted using the ABCD rule in traditional skin cancer identification, performing malignancy triage followed by subtype classification across eight lesion categories. The model was trained on 15,724 images from the HAM10000 and ISIC 2019 datasets, and it achieves 94.27% accuracy in classifying a skin lesion as either benign or malignant, 94.4% accuracy in classifying malignant skin lesions, and 98.6% accuracy in classifying benign skin lesions. For the final systems, which integrate the neural network with a Raspberry Pi device and a smartphone app, end-to-end validation across 50 trials displays 100% completion rate with response time under one second on both platforms, both without cloud dependency. Our system demonstrates that clinically actionable, real-time skin cancer triage is achievable on commodity hardware, offering a scalable approach to at-home early detection.

Noble And Greenough School

**HandSplatter: Automated Digital Goniometry Using Neural Rendering**

Emmett Chen

I present a pipeline to obtain a full 3-D model of the hand and finger range-of-motion (ROM) using only using smartphone photographs.
Millions of individuals injure their hands annually, and ROM is an important measurement for informing surgical decisions. The current tool for measuring ROM is the goniometer, which is inefficient and painful for injured patients. Consequently, many hand clinicians skip this measurement.
Ideally, we replace the goniometer with a digitized alternative. 3-D hand reconstruction for clinical use is under-explored in computer vision. This project employs 3-D Gaussian Splatting from the new field of Neural Rendering to reconstruct a 3-D model of the hand from photographs and obtain high-fidelity finger joint locations. I introduce two new 3-D landmark refinement algorithms, “Hillclimbing” and “Lean” which substantially correct estimated joint positions using the generated hand as a geometric prior. This algorithm was validated against the goniometer for 20 subject hands, demonstrating reasonable agreement with goniometry per Bland-Altman analysis. Our ablation test showed improved agreement with goniometry when using an iterative joint refinement algorithm versus no adjustment of estimated joint regions. Future work will focus on improving image acquisition protocols and hand joint schematics.
Overall, this pipeline for obtaining ROM from photographs is a robust tool for painless and efficient measurements in office, inpatient, home, or telehealth settings, potentially allowing for faster, more informed clinical care; moreover, this work is highly generalizable to other 3-D objects, potentially making it a lightweight 3-D reconstruction and landmarking engine only needing photographs from a smartphone.

Keywords—3-D Reconstruction, 3-D Gaussian Splatting, Neural Rendering, Hand, Finger, Range of Motion, ROM

**Noninvasive Skin Hydration Monitoring Using Skin Conductivity**

Shaymaa Mourchid

Maintaining hydration is essential for good health, but continuous monitoring can be impractical. The goal of this project was to design a wearable hydration monitoring device that measures the conductivity of one's skin and converts it into resistance (kiloohms) to determine their hydration level. This device uses an Arduino Uno Board connected to Grove GSR sensors, which contain finger straps to measure electrical resistance through the skin. A voltage-divider circuit allows the Arduino to convert skin resistance into digital readings that are recorded and displayed on a computer that is connected to the Arduino via a USB cable. The expected outcome was that the device would detect changes in skin resistance after a person drinks a certain amount of water, demonstrating its ability to track hydration trends.

To test the device, participants placed two fingers into the sensor straps, and their initial hydration readings were recorded. Each participant drank 18 fluid ounces of water. Then, every 10 minutes for an hour, their hydration readings were taken and recorded. The results of the test showed a decrease in skin resistance relative to the initial hydration level for all participants, indicating that the device is reliable for detecting changes in resistance trends associated with hydration changes.

While the device successfully demonstrated its functionality, potential limitations and errors include: environmental interference, motion artifact, and individual physiological variability. Future improvements could be made by implementing a temperature detector in the advice, integrating accelerometers to track motion, and creating personalized calibration for the user by incorporating demographic features as additional inputs for the program. This device has the potential to be a health product, because it can be used by various individuals, such as older adults, people exposed to stressful environmental conditions, or patients with poor hydration habits or dehydration.

Mansfield High

**Analysis of the Hyperextension of the Tibia Relative to the Femur to Indicate the Laxity of the Anterior Cruciate Ligament within the Human Knee.**

Ava Aquino

Anterior Cruciate Ligament (ACL) tears have drastically risen and become common season ending injuries for athletes. The ACL is one of the four major ligaments within the human knee that connects the femur to the tibia, providing stability and support during movement. Despite the alarming statistics behind ACL tears (i.e. - female athletes have 3x higher risk of sustaining an ACL injury compared to men), research has failed to find the exact cause of ACL injuries among athletes. It is known that the ACL provides about 85% of the total resistance force during anterior tibial translation (the tibia bone moving forward relative to the femur bone), indicating that greater anterior knee laxity (AKL) can be used as an ACL injury predictor.

This proof-of-concept experiment used artificial knee models with three ACL conditions (normal, torn and no ACL) to measure tibial bone hyperextension relative to the femur. Three wooden mounts were constructed to hold the knee models in place. Sensors then measured the amount of hyperextension each model presented. Each of the 3 models were documented for 3 trials-leading to a total of 9 documented trials overall.

Through the calculations of a T-Test ($p=0.05$), the data validated that there was a significant difference when comparing each ACL condition. A one-tail T-Test calculation presented: normal ACL vs torn ACL ($p=0.000222$); torn ACL vs no ACL ($p=2.78E-07$); normal ACL vs no ACL ($p=1.73E-06$). A two-tail T-Test calculation presented: normal ACL vs torn ACL ($p=0.000443$); torn ACL vs no ACL ($p=5.56E-07$); normal ACL vs no ACL ($p=3.47E-06$).

The results indicate that there is a great connection between the condition of an ACL and the measurable amount in which the tibia hyperextends past the femur; the hyperextension would indicate a torn or weakened ACL compared to a baseline. This experiment and its findings may show that greater AKL can be an ACL injury predictor, along with proving that the AKL is measurable. Future research should investigate the correlation between ACL conditions and AKL on athlete's knees at the beginning, throughout and the end of their sports season; comparing fluctuating AKL values.  The hope is to identify the potential risk of an ACL injury before an athlete sustains one.

North Attleboro High

**The Detection of Breast Cancer Cells using Artificial Intelligence (AI)**

Nainika Bodapati

Breast Cancer is one of the most common cancers around the world and in fact, the leading cause of deaths in women. Early detection of these cells will greatly improve the survival rate of people who have this cancer type because studies show that there have been 42,680 deaths in the United States alone. This project's main goal is to assist doctors and medical professionals by speeding up the process of detecting early signs of Breast Cancer, preventing it before it can get to the stage of being life-threatening. By using already existing data in the form of x-ray pictures from the National Cancer Institute (NCI), we can train the AI model to identify/recognize patterns that distinguish cancerous cells from non-cancerous cells (normal cells). In the end, this model will be able to analyze features such as cell shape, size, and texture. After training is over, its accuracy will be tested by importing new x-ray results that it hasn't been trained with. Once done, we have a fully functional program that can speed up the process of diagnosis, helping medical professionals get started on treatments early on, therefore, preventing many deaths. This study overall goes to show that Artificial Intelligence can be a powerful tool for improving early Breast Cancer detection and making medical analysis more efficient.

Concord Academy

**From Ocean to Oncology: Harnessing Seaweed for Targeted Colorectal Cancer Drug Delivery**

Loanne Kim

Colorectal Cancer (CRC) ranks among the deadliest cancers in the U.S.; however, current treatment options remain limited due to the lack of effective drug delivery systems. Conventional oral and intravenous administration methods distribute the medication systematically, causing severe side effects while failing to achieve optimal therapeutic concentrations. This study therefore introduces an innovative drug delivery system (DDS): seaweed-based pockets capable of safely transporting colorectal cancer treatments to the large intestine. Kelp pockets were evaluated for durability via incubation in Simulated Salivary Fluid (SSF), Simulated Gastric Fluid (SGF), and Simulated Intestinal Fluid (SIF). Human colorectal cancer cell lines (HCT116) were treated with a sodium alginate-calcium chloride-green fluorescence microplastic (SA-CaCl□-GFMP) complex to assess cellular uptake; HCT116 cells were also treated with anticancer medications combined with various seaweed extracts to check for treatment interference. The degradation of kelp pockets was further observed in SIF with and without gut microbiota. While the kelp pockets remained intact in SSF and SGF, they were digested and broken down in SIF containing lactic acid bacteria and E. coli. Furthermore, HCT116 cells incorporated the SA-CaCl□-GFMP complex better than non-treated GFMP; seaweed extracts did not interfere with the effectiveness of anticancer drugs, validating their compatibility as carriers. These results thus demonstrate that kelp pockets provide a safe, targeted, and promising DDS for CRC that enhances therapeutic precision while reducing systemic toxicity. Accordingly, leveraging seaweed as a natural and biodegradable drug delivery device (DDD) looks to promise an exponential enhancement to the effectiveness of CRC treatments.

Winchester High School

**Migr[AI]ne Chill(™): AI-Enabled Wearable Device for Providing Noninvasive Migraine Therapy**

Caleb Swilling, Lily Swilling

Migraine is a debilitating neurological disorder affecting over 148 million individuals worldwide, often characterized by Autonomic Nervous System (ANS) dysfunction. While pharmacological treatments exist, they are often unsuitable for children, pregnant individuals, or treatment-resistant patients, demanding a safe, non-invasive alternative. The goal of this research was to develop MIGR[AI]NE Chill, a closed-loop wearable device integrating three clinically-validated modalities: cryotherapy (thermal), kinetic oscillation (mechanical), and green light phototherapy (optical).

The engineering process involved the development of three prototyping stages: a rudimentary, light analgesic soft-headband, a breadboarding prototype, and a full system integrated prototype as a wearable head device. This final wearable runs on a custom PCB paired with an Arduino Nano 33 BLE Sense, a hardware setup that unlocks smart, adaptive treatment using the board's machine learning capabilities. To enable predictive treatment, a TinyML model was developed using a Random Forest Classifier to monitor Heart Rate Variability (HRV), a biomarker of oncoming migraine, in real-time. The model was trained on high-stress (low HRV) and baseline (high HRV) datasets, achieving a validation accuracy of 99.20%. This edge-computing framework was integrated with a user-friendly mobile application to provide real-time alerts and user-defined intensity control.

Testing of the integrated Prototype 2 confirmed the system's ability to successfully modulate Peltier-based cooling, 1-50 cd/m2 green light, and vibrational frequencies upon detection of ANS strain. Results indicate that the device provides a standardized, user-based adaptive treatment and accompanying phone application that remains energy-efficient and portable. Ultimately, this research demonstrates that combining AI with physical therapies can provide effective, drug-free migraine relief, offering a safe alternative for patients who cannot take traditional medication.

Winchester High School

**Dietary Antioxidants Protect the Intestinal Barrier: Evidence from an Inflamed Human Cell Model**

Daniel Chen, Alan Wang

Diet significantly influences human health, with the intestine serving as the primary site of nutrient absorption and a critical protective barrier against harmful substances. Disruption of this intestinal epithelial barrier can lead to inflammation and contribute to various diseases. While foods rich in antioxidants are widely believed to support gut health, direct experimental evidence in human cell models remains limited. This study tested the hypothesis that digested foods with higher antioxidant content protect intestinal barrier integrity during inflammation. We used Caco-2 cells, a well-established human intestinal epithelial model, grown on Transwell inserts to form polarized monolayers mimicking the gut lining. Spinach and bread were subjected to in vitro chemical digestion to simulate gastrointestinal processing; spinach digesta exhibited substantially higher antioxidant levels than bread digesta. Digesta samples were applied to Caco-2 monolayers under preventive (pre-inflammation) and therapeutic (post-inflammation) conditions. Inflammation was induced using a standard cocktail (cytokines/LPS). Barrier function was assessed via transepithelial electrical resistance (TEER), tight junction protein localization by immunofluorescence, and surface morphology by scanning electron microscopy. Results showed that pretreatment with spinach digesta significantly maintained TEER stability and reduced inflammation-induced barrier damage compared to bread digesta. Post-inflammation application, however, failed to restore barrier integrity. These findings provide direct evidence that digested spinach, likely due to its elevated antioxidants, protects the intestinal barrier in a human cell model and highlights the protective potential of antioxidant-rich foods against gut inflammation. This supports the use of controlled in vitro systems to explore diet-gut interactions and informs future dietary strategies for intestinal health.

Keywords: Intestinal barrier function, Simulated digestion, Dietary antioxidants, Inflammation model, Caco-2 epithelial cells

Littleton High School

**Non-Invasive Iron Deficiency Detector to Improve Early Detection of Iron Deficiency without Anemia Utilizing the Properties of Zinc Proportion Fluorescence**

Anika Gosukonda

Iron deficiency without anemia (IDWA) is the most common nutritional deficiency worldwide due to its non-specific symptoms and the lack of a single accessible test. The objective of this project was to create a device capable of detecting various concentrations of curcumin fluorescence for future applications with zinc protoporphyrin fluorescence in non-invasive IDWA diagnosis.

The design criteria for this device included a cost of less than $35.00, size less than 9inx7inx2in and 5lbs, results within one minute of testing, and a relative standard deviation less than 5%. The non-invasive iron deficiency detector (NID) was developed iteratively using four prototypes, testing basic circuitry, implementing experimental structural materials, and finally, refining 3D printing.

The NID detector detects fluorescence with high precision, accuracy, and extremely strong confidence in significance through 13/14 post-hoc Tukey Range tests ($p < 0.01$), with each concentration's relative standard deviation being less than 1%, and a clear downward trend in mean receiver-capacitor counts. This data was based on the principle that the number of receiver-capacitor counts decreases as light intensity increases.

With minor changes to the optical filter, added spectral fitting, and a calibration curve, the NID detector has the opportunity to aid in the mitigation of iron deficiency without anemia globally. It also maintains practicality, accessibility, and portability by exceeding the project's design criteria. Overall, these results indicate the device's strong potential to improve anemia detection worldwide, aligning with the project's goal to make an impactful contribution to world health.

**Detecting Wound Infections via pH and Temperature Sensing**

Devon Striek, Harinekshane Lingam, Sreenisha Rajesh

Wound infections impact millions annually and often go undetected until hospitalization or amputation. Current methods, such as tissue biopsies, swab testing, and the new Smart Sutures development, are invasive, expensive, and slow. We questioned whether we could build a device that detects wound infections faster than existing methods. Our project tests whether a non-invasive, affordable bandage can continuously monitor pH and temperature to detect infections. Because infected wounds become more alkaline and warmer, we hypothesized that tracking these variables would enable early detection with a false-positive rate below 5%. We built a prototype using calibrated pH and temperature sensors connected to an ESP32 microcontroller programmed in C++ to collect, process, and display real-time data on an LCD screen. To fix portability limitations, we designed an external liquid-testing chamber that pumps wound fluid to the pH sensor while the temperature probe directly contacts the wound surface. Our sensors were validated against professional meters. We tested the device using yeast grown in a petri dish for 4 to 5 days as a biological source since pH and temperature change noticeably during fungal growth. We collected 24 data points total, 6 per device, over five days under controlled conditions. The results showed percent errors of 1.01% for pH and 2.06% for temperature, with no significant differences compared to professional equipment. For future plans, we hope to reduce the bulk by removing tubing, minimizing sensors, and integrating Bluetooth connectivity with a smartphone app for continuous wireless monitoring and real-time alerts.

**Automated, Affordable Pill Dispenser to Support Caregivers and Individuals with Memory Challenges**

Sanskar Acharya

Over 57 million people worldwide live with dementia, many of whom must manage complex medication regimens. According to the Centers for Disease Control and Prevention (CDC), nearly 90% of adults aged 65 and older take at least one prescription medication annually; however, adherence among cognitively impaired populations can be as low as 10–38%, highlighting a substantial gap in safe medication management. Existing pill dispensers are often costly, rely on inefficient manual handling, or are difficult to set up, limiting accessibility for patients and caregivers. Preliminary stakeholder survey responses emphasized affordability as a critical factor and reinforced the need for simple, automated dispensing systems. This project developed a low-cost, fully automated pill dispenser designed to improve adherence while minimizing mechanical complexity.

The system uses an ESP32 microcontroller to control four independent microservo-driven compartments. Each compartment rotates 180° to deliver a single dose at scheduled times, supported by synchronized LED and buzzer alerts. The structure combines laser-cut acrylic and 3D-printed components, allowing home fabrication at a material cost of $87 USD. All code and mechanical designs are open source to encourage replication.

Mechanical testing with spherical marble balls as simulated pills demonstrated very high reliability, with all four compartments achieving 100% single-dose accuracy across ten trials. Preliminary surveys indicated strong interest in automated dispensing technology, with the vast majority of respondents noting it would be highly helpful in supporting patients' medication routines. The device is designed for simplicity: the user only needs to ingest the pills from the tray, and setup is straightforward with an intuitive interface.

Although caregiver usability testing is ongoing, this prototype demonstrates the feasibility of an inexpensive, community-informed solution that may reduce caregiver burden and improve adherence for individuals with memory challenges. With further refinement, this system has the potential to expand access to practical, scalable assistive healthcare technology.

Buckingham Browne & Nichols School

**DermaSpectra DeepVision: A Multispectral Imaging System for Enhanced Dermatologic Diagnosis Powered by a Novel CNN–Transformer–LLM Framework**

David Guo

Skin disease is a major rising burden, with over 6.6 million annual skin cancer diagnoses worldwide; earlier detection markedly improves survival. In youth, eczema affects up to 30% of children and acne affects 85% of adolescents, driving scarring and primary-care overload.

Standard RGB-only diagnostic tools are limited to capturing visible, surface-level symptoms, missing critical subsurface biomarkers (e.g., microvascular remodeling, hemoglobin/melanin shifts). Without deep-tissue data, clinicians cannot accurately distinguish benign from malignant lesions, assess true severity, or delineate lesion margins. Professional spectral tools capture these subsurface biomarkers but remain prohibitively expensive and require specialized training. To address these barriers, this research makes the following contributions:

• Engineered a low-cost (<$500), end-to-end multispectral imaging system powered by a unified multi-disease explainable AI framework for accurate screening and diagnosis.

• Developed a portable multispectral imaging device that captures subsurface biomarkers that RGB-only tools cannot detect, enabling earlier and more accurate assessment.

• Developed a hybrid 7-channel physics-informed CNN-Transformer architecture that simultaneously classifies multiple diseases and stages severity with improved accuracy.

• Overcame the scarcity of clinical hyperspectral datasets scarcity by engineering skin phantoms that mimic the light-scattering physics of human skin.

• Achieved Sim-to-Real domain adaptation via spectral-spatial calibration, utilizing transfer learning to map domain-invariant spectral ratios from silicone phantoms to human skin. Additionally, the system can computationally reconstruct a high-fidelity 31-band clinical spectrum from 7 multispectral inputs.

• Developed a RAG-enhanced LLM mobile application that translates deterministic spectral data into actionable clinical reports for primary care physicians, while providing safe, explainable triage guidance for at-home screening.

Keywords: multispectral imaging, RGB–spectral fusion, hybrid CNN–Transformer, spectral calibration, spectral reconstruction, subsurface biomarkers, skin phantoms, sim-to-real domain adaptation, RAG-enhanced LLM, point-of-care diagnostics, explainable AI, early detection.

Lexington High

**VoxNeuro: A Low-Cost, Accessible Multimodal System Integrating Wearable Gait Monitoring and Grassmannian Subspace Analysis of Speech for Parkinson's Screening**

Laiba Khan

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Parkinson's disease (PD) affects over 10 million people worldwide and is the fastest-growing neurological disorder by prevalence, disability, and mortality. Early detection remains a critical unmet need, as motor symptoms typically emerge only after substantial dopaminergic neuron loss. Speech and voice degradation, hallmarks of PD-related hypokinetic dysarthria, offer a promising non-invasive biomarker avenue, yet existing machine learning approaches to PD speech classification frequently suffer from inflated accuracy estimates due to subject leakage when repeated measurements are naively treated as independent samples.

We propose VoxNeuro, a geometry-aware classification framework that addresses this methodological gap by representing each subject's replicated speech recordings as a point on a Grassmann manifold and fusing subspace-based and Euclidean summary kernels through a positive semidefinite multi-view scheme. To handle class imbalance, we introduce Geodesic SMOTE (G-SMOTE), which synthesizes minority-class subjects along manifold geodesics rather than in Euclidean space. All evaluations enforce strict subject-disjoint cross-validation folds with within-fold standardization.

We validate the method on two publicly available replication-based datasets spanning distinct feature regimes: a balanced 80-subject replicated acoustic feature set (UCI-489) and an imbalanced 252-subject high-dimensional engineered speech corpus (PD-252, 753 features). On UCI-489, the proposed method achieves a balanced accuracy of 0.850 ± 0.042 and macro-F1 of 0.847 ± 0.043, representing improvements of approximately +7.5 and +7.7 percentage points over the strongest baseline, respectively. On PD-252, it attains 0.747 ± 0.036 balanced accuracy and 0.756 ± 0.029 macro-F1, maintaining top rank under feature-regime shift and severe class imbalance. Permutation importance analysis identifies tunable Q-factor wavelet transform features as the most predictive family, consistent with prior acoustic characterizations of parkinsonian speech.

In addition, we incorporated gait data as a complementary modality and developed a low-cost wearable sensor for continuous, real-world monitoring, positioning the framework as an accessible and scalable multimodal platform for Parkinson’s screening. Our results show that repeated speech and gait measurements, modeled through manifold-based learning with leakage-safe evaluation, capture stable disease-relevant signatures across heterogeneous datasets. This highlights the feasibility for earlier, more accurate detection and monitoring of Parkinson’s disease in homes, annual screenings, and clinics with limited specialist access.

Keywords: Parkinson’s disease, Inertial Measurement Unit (IMU), low-cost multimodal wearable sensing, motor speech biomarkers, gait analysis, Grassmannian geometry, manifold-based learning, repeated-measures modeling, support vector machines, cross-dataset generalization, multimodal assessment.

**Intelligent Impact-Sensing Liner for Youth Female Athlete Safety**

Charlotte Corbin

Youth female athletes experience disproportionately high rates of unrecognized concussions because existing protective equipment is often designed for male biomechanics. To address this disparity, this project developed a low-cost, intelligent helmet liner optimized for female youth lacrosse players, integrating a system containing an IMU, accelerometer, and gyroscope within a flexible EVA-based foam structure. Laboratory drop and oblique impact tests validated the design, revealing that the integrated sensors recorded 6-degree-of-freedom kinematics with over 90% correlation to reference standards while providing significant impact attenuation. By translating raw data into immediate concussion-risk alerts, this device bridges the critical gap between impact occurrence and clinical intervention. Ultimately, this scalable safety solution empowers families with real-time feedback, reducing the risk of second-impact syndrome and improving long-term health outcomes for young female athletes. This prototype confirms that a data-driven, ergonomic approach—including a ponytail-compatible design—can significantly reduce injury risk. The system had a high correlation in detecting high-risk impacts while maintaining brain tissue strain at 7.6%, well below the 15% injury threshold, providing a nearly 50% safety margin for youth female athletes.

Keywords: concussion detection, impact sensing, female, athletes, helmet liner, rotational acceleration, sports engineering, youth safety

Middlesex School

**Nanosensing of Neurofilament Light Chain for Early Amyotrophic Lateral Sclerosis Diagnosis**

Linghang Yu

Amyotrophic Lateral Sclerosis (ALS) is one of the deadliest diseases with only medications to prolong survival and improve life quality after diagnosis. Currently, most doctors diagnose ALS by capturing progressing symptoms, therefore delaying the diagnosis by months and even years, directly shortening the patient’s life expectancy. This makes a quantitative way to diagnose patients early crucial. Neurofilament Light Chain (NFL) is a promising biomarker in both CSF and blood to a host of neurodegenerative diseases, including ALS. However, the trace amounts of Neurofilament Light Chain in blood requires ultrasensitive technology to detect
and current methods that are capable of this level of sensitivity are extremely inaccessible around the world.
Surface-Enhanced Raman Spectroscopy (SERS) would be a great solution to this problem, combining high sensitivity, cheap cost and simplicity. In this research, we used silver nanoparticles for enhancement to
conduct a label free Raman detection of NFL in distilled water and in synthetic blood. The results showed that neurofilament light chain concentration in distilled water linearly correlated with both Raman intensity and area under peak, with R^2 values of 0.965 and 0.97 respectively. Furthermore, we found that it is feasible to detect and differentiate concentrations of NFL in synthetic blood with further research.

Grafton High School

**Robotic Medication and Cognitive-Assessment App to Enhance Memory Retention in Alzheimer’s Patients**

Sullivan McCarthy, Vinesh Kanagavel Chithra

Alzheimer’s Disease is a disease that causes a decline in cognitive ability over time, affecting neurons in the brain. As symptoms worsen, many Alzheimer’s patients visit their doctors for expensive treatments, which can be time consuming and dangerous for the elderly. However, there is new research to show that by using reality orientation, or, exposing patients to social scenarios (in the form of a quiz), the effects of Alzheimer’s can be reduced. To combat the effects of Alzheimer's and increase convenience for the patient, we created an application that connects to a robot that will use reality orientation and medication dispensation to stimulate cognitive and social interaction. To begin our project, we created an app that can be accessed by the caretaker, and serves as a control center. This app allows the caretaker to edit medication information and quiz information. Once this data is published to a real-time database, it can be read by an ESP32 microcontroller, which connects to a motor and screen for the patient experience. To start building the robot, we 3D printed a base box and disks that would hold the medication. Once the information was received, the motor, coded in C++, would turn and drop the corresponding medication down through a tube to the patient. In addition, the information surrounding the cognitive quiz would be printed on a screen, with a keypad accessible for patient interaction. Ultimately, this incredibly inexpensive system of app and robot interaction was successful, and based on the results of reality orientation studied by a group of researchers in Brazil, we can conclude that if interacted with everyday, the system will help to slow the effects of Alzheimer’s while still promoting organization and convenience in the patient’s life.

**Striking the Mind: A Low Cost, AI Powered EEG Sensor Measuring Alpha and Beta Wavelengths.**

Omer Abdelwahab

Electroencephalography (EEG) sensors are tools used to measure cognitive metrics, including focus and stress. However, most EEG systems are expensive and use multi-electrode systems with complicated software, creating a barrier for many non-clinical researchers. This project aims to build and test a low-cost, portable, four-electrode EEG system that uses machine learning to determine whether meaningful alpha (8–12 Hz) and beta (13–30 Hz) brainwave activity can be reliably extracted using simplified hardware.

An Arduino-based EEG interface was constructed using four electrodes on the scalp. The EEG uses signals that are preprocessed with band-pass filtering and artifact rejection. The signals are then analyzed using a regression-based machine learning model that converts electrical signals into meaningful cognitive metrics such as focus and stress. Validation included increased alpha activity during eyes-closed conditions, beta dominance during mentally demanding tasks, and characteristic low-frequency artifacts during eye blinks. Trials were repeated and compared to surveys from 57 participants using correlation analysis.

Results demonstrate that the system can distinguish alpha- and beta-dominant states with 80% accuracy (ability to detect alpha and beta dominance), similar to EEGs with more complex setups. Affordable EEG hardware with AI-based analysis can provide meaningful cognitive insights, lowering barriers for non-clinical science research.

Groton School

**Bionic Skin: A Multimodal Sensor-Based Artificial Skin for Diabetic Foot Ulcer Prevention**

Damien Li

This project reconsiders the intrinsic mechanism of diabetic foot ulcers (DFU) from a biomechanical perspective, proposing that ulceration is not a sudden pathological event, but rather the result of accumulation. The condition occurs only after multi-axial fatigue has accumulated following the loss of plantar protective regulation (PPR). Inspired by the sensory and functional regulation of human skin, I designed a multimodal bionic skin silicone insole capable of real-time monitoring of vertical pressure, shear stress, temperature, humidity, and visual changes in skin features. A key innovation of this project is the development of a shear force sensor based on silicone deformation, enabling cross-monitoring of shear force and vertical pressure. Using the shear-to-pressure ratio (SPR) framework combined with the von Mises stress model, I verified that even when the overall pressure appears moderate, certain transient shear-dominant events can increase the equivalent tissue stress by up to 258%; if such events persist over time, they can significantly elevate the risk of ulceration. The creation of a personalized AI gait recommendation system based on the current gait phase of the user, predicted peak Von Mises stress, and current mean SPR, was also a major innovation of my product.

Billerica Memorial High School

**Forecasting Structural Knee Osteoarthritis Progression with Multimodal AI**

Ishaan Rana

This project explores whether knee osteoarthritis progression can be predicted years in advance using baseline X-rays and basic clinical information. The work uses de-identified data from the Osteoarthritis Initiative, which includes baseline knee radiographs, follow-up KL grades, and clinical measures such as age, BMI, pain scores, and baseline KL. All images were standardized through cropping and normalization, and clinical variables were cleaned, imputed when needed, and scaled for modeling.

Three types of models were tested: one using only X-ray images, one using only clinical data, and one that combines both. Each model was evaluated with subject-level data splits to avoid leakage, using metrics such as AUC-ROC, AUC-PR, sensitivity, and specificity. The combined model performed the best overall, suggesting that imaging and clinical information provide complementary signals for identifying knees likely to worsen over the next 4–7 years. Interpretability tools showed that the models focused on meaningful OA features such as joint space narrowing and key clinical factors like BMI and age.

The results show that multimodal AI approaches may help flag higher-risk patients earlier, supporting more proactive monitoring and treatment strategies in knee osteoarthritis.

Westford Academy

**Non-invasive Glucose Monitoring Using Multi-Wavelength Optical Polarimetry**

Austin Lin, Jaden Chen, Saayan Rao

Current diabetic management is still hindered by the invasive nature of "finger-prick" glucose monitoring, which leads to patient discomfort, infection risks, and high costs. While optical non-invasive methods (NIR spectroscopy, Raman etc.) have been extensively researched, they are skin-based modalities and fundamentally limited by high tissue scattering and physiological variability. This research proposes an alternative: a multi-wavelength polarimetric system (400 nm, 532 nm, and 635 nm) targeting the aqueous humor of the eye. By leveraging the eye's optical homogeneity and low scattering, the system measures the optical rotation of glucose's chirality—a potential clean biomarker to measure diabetes. Furthermore, the use of three distinct wavelengths enables simultaneous acquisition of spectroscopic data, similar to the skin case but with a clean optical path. Multivariate models can be built for the potential decoupling of corneal birefringence and the distinguishing glucose anomers to improve clinical accuracy. With our prototype, we were able to measure sub-degree rotations in glucose which corresponds to a magnitude of 100mg/mL.

Groton School

**Expanding Access to Hematologic Diagnostics with HEMAger: An AI-Powered 3D-Printed Microscopy Platform With Blood Smear Preparation Pipeline for Resource-Limited Settings**

Ethan Yan

The diagnosis of blood disorders remains challenging due to the lack of access to timely and accurate blood examinations, especially in underresourced areas. To address this issue, this research develops HEMager, the first 3D-printed low-cost portable microscopic imaging system and blood smear preparation pipeline powered by AI for blood disorder detection. HEMager comprises three innovations: a cost-effective, high-resolution imaging system, a blood staining system that can be used in both clinic and non-clinic settings, and an AI system to localize and classify red blood cells and white blood cells. The imaging system comprises a 3D printed microscope, achromatic objective, Pi Camera, and Raspberry Pi 4B, with X, Y, and Z-axis adjustment and 0.7μm resolution, costing less than $20 and weighing less than 1 kg. A simple, quick, and effective blood smear preparation pipeline was developed using a drop of finger-stick blood and a staining process lasting less than 30 seconds. Computer vision analysis showed that the stained red blood cells had optimal variance of Laplacian and saturation values and that the stained white blood cells had similar nuclear optical density and cytoplasm optical density to those of laboratory-standard stained blood cells. Furthermore, two YOLOv12-based deep learning models were developed to detect normal and abnormal red blood cell and white blood cell disorders, with precision, recall, and mAP50 of ~80%. With all the components integrated, a drop of blood from the student researcher was used to test the platform, which demonstrated that HEMager accurately detected the blood cells. In addition, HEMager successfully detected sickle cell disease, acute leukemia and chronic lymphocytic leukemia. HEMager can be readily deployed in small clinics without specialized health professionals, school health centers, or even at home, and it has the potential to significantly improve access to blood disease detection.

Key Words: hematologic diagnostics; artificial intelligence; portable microscopy; blood smear analysis; deep learning; accessible diagnostics

**Video-Based Measurement of the Pupillary Light Reflex for Baseline Neurological Analysis**

Hemant Selvamurugan

The pupillary light reflex (PLR) is an automatic neurological response in which the pupil constricts in response to light and is commonly used in clinical assessments of brain function. The purpose of this study was to quantify baseline PLR characteristics using a low-cost, video-based measurement approach. Eye response was recorded under controlled lighting conditions using a smartphone camera, and pupil diameter was analyzed frame-by-frame to extract baseline diameter, minimum diameter, constriction magnitude, and response time. A total of 30 trials were conducted across 10 participants. The results showed consistent pupil constriction across participants, with an average change of approximately 33 pixels and an average response time of 0.55 seconds. A positive relationship was observed between baseline and minimum pupil diameter, indicating proportional scaling of pupil response. These findings demonstrate that video-based analysis can reliably quantify pupil dynamics and establish baseline values for future development of accessible optical neurological monitoring systems.

Boston Latin School

**Characterizing Cellular and Molecular Drivers of Diabetic Retinopathy through Bioinformatic Analysis of Transcriptomic Data from Patients**

Olivia Chen

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Due to the high prevalence of diabetes mellitus (DM), diabetic eye disease remains a leading cause of blindness in our country and around the world. The goal of this project is to understand complex biological networks and cellular and molecular functions underlying diabetic eye disease, with the aim of identifying novel biomarkers and targetable pathways that may help combat this debilitating condition. In this study, I conducted bioinformatic analyses of a single-cell transcriptomic dataset, integrating qualitative and quantitative approaches using computational biology methods that involve coding tools and biological databases. The selected dataset is a 10x Genomics–based transcriptomic profile generated from pathological retinal tissue obtained from patients with diabetic retinopathy (DR). I performed Uniform Manifold Approximation and Projection (UMAP), Differential Gene Expression (DGE), and Gene Set Enrichment Analysis (GSEA) to identify enriched biological pathways in the full dataset and in a macrophage subset (a major cell type in disease tissue). UMAP analysis indicated that pathological retinal tissue from DR patients is composed primarily of vascular endothelial cells, fibroblasts, macrophages, memory CD8☐ T cells, and pericytes, consistent with its fibrovascular nature. GSEA revealed that MYC Targets and Epithelial–Mesenchymal Transition pathways are among the most upregulated biological programs in these pathological cells. Further analysis of the macrophage subset showed that macrophages within DR tissue exhibit both M1 (pro-inflammatory) and M2 (pro-fibrotic) subtype characteristics and display strong activation of the TNF-α/NF-κB signaling pathway. These findings suggest that targeting this pathway provides dual therapeutic benefits by reducing both inflammation and fibrosis in DR.

**A Low-Cost Edge Sweat Sensor That Audibly Alerts Athletes of Rising Dehydration Risk**

Dhanusha Ramadas

Many athletes, including myself, have trouble keeping track of their hydration while working out. Many people don’t know how to pace themselves and how to time their water intake, finding themselves fatigued or even dehydrated by the end of their workout or training. This low-cost sweat sensor detects dropping hydration levels and alerts athletes when they are at the risk of dehydration so they can hydrate accordingly. The sweat sensor detects the NaCl levels in the sweat, if the NaCl levels cross a certain point the sensor with then audibly alert the user of dehydration.

Andover High

**Automated Dental Caries Detection and Risk Classification Using YOLOv8 Object Detection and a Custom Cavity Risk Scoring System**

Nav Garg

Dental caries is a chronic disease caused by bacterial erosion on the tooth enamel, making it one of the most widespread conditions globally, affecting approximately 2.3 billion people. Despite preventive measures, cavities often go undetected due to variability in detection accuracy among dental practitioners, often leading to more invasive and costly procedures for the patient. This project aimed to address three key challenges in current dental practice: the need for a more standardized procedure for caries detection, the opportunity to support practitioners in efficiently analyzing bitewing and periapical radiographs, and the goal of effectively communicating the impact and location of dental caries to patients. Using transfer learning, a YOLOv8 object detection model was designed, trained, and evaluated to detect and localize dental caries in bitewing and periapical X-rays. Along with binary classification, this system outputs bounding boxes revealing the location of each cavity, providing a visual aid to both the practitioner and the patient. A custom Cavity Risk Scorer was also developed to assign each detected cavity a severity level of LOW, MEDIUM, or HIGH based on size and detection confidence. The model was trained on a publicly annotated dataset prepared through Roboflow. The system achieved an accuracy of 87.5%, exceeding the 85% design criteria, with a precision of 98.5%. These results demonstrate that the system effectively detects the presence of dental caries above the accuracy threshold, with further work needed to improve recall through dataset expansion.

**Evaluating Machine Learning Models for Predicting Ciprofloxacin Resistance in Escherichia coli using Genomic Features**

Meghna Nambiar

Antibiotic resistance in Escherichia coli is a growing public health concern, particularly resistance to ciprofloxacin, a commonly prescribed antibiotic for urinary tract and bloodstream infections. This study examined whether machine learning models could accurately predict ciprofloxacin resistance in E. coli using genomic data from a publicly available dataset of 1,935 clinical isolates collected in the UK between 1970 and 2017. A computational prototype was developed using accessory gene presence and absence data, or whether specific genes were present or missing in each bacterial sample. Three models were trained and compared including a baseline classifier, a full Random Forest using all 17,198 gene features, and a restricted Random Forest using only the top 20 most important genes. The full Random Forest achieved 93.8% accuracy, significantly outperforming the baseline model at 77%. Cross validation confirmed this result with an average accuracy of 92.5% across five tests. The restricted top 20 feature model achieved 89.9% accuracy, suggesting that a small targeted gene panel is a strong predictor of resistance. The cat gene was identified as the most important predictor, which may indicate co-resistance mechanisms across antibiotic classes. A total of 17 false negatives were identified, representing cases where resistant bacteria were incorrectly classified as susceptible, the most clinically dangerous type of error. These results suggest machine learning is a promising tool for rapid resistance prediction. Future research should incorporate gyrA specific mutation data, larger datasets, and additional models to improve clinical applicability and accuracy.

**Sensor-Based Multi-DOF Exoskeleton System for Running Form Analysis and Injury Rehabilitation**

David  Chen

This study develops a lightweight exoskeletal device based on wearable sensing and generative design for gait monitoring during trail running. In trail running and other running sports, leg movements, arm swing and torso posture directly affect athletic performance. To solve the limitations of existing commercial wearables (inability to perform joint-level motion capture, lack of terrain adaptability, and absence of real-time feedback), this project proposes an active monitoring device that uses high-precision angle sensors, an embedded system, and generative design methodologies. Structural modeling and generative optimization were conducted using Autodesk Fusion 360, combined with 3D printing technology and PETG-CF material. As a result, I made a final prototype featuring a lightweight design with weight reduction from 547.5g in the initial design to 373.8g. The system consists of 21 components, integrating 8 sets of joint angle sensors and triaxial gyroscope data. Data acquisition and Bluetooth transmission are implemented via an ESP32 microcontroller, while a real-time data visualization and analysis interface is developed on a PC platform. Through multiple rounds of structural iterations (3 major versions, 84 minor iterations) and field testing, the device demonstrates great wearing comfort, data stability, and motion capture capabilities. The results from my research show that this device can capture three-dimensional motion characteristics of the arms, shoulders, torso, and knee joints during trail running. This allows runners to get access to high-quality gait feedback and offers a feasible technical pathway for future development of intelligent assistive and rehabilitation devices.

Roxbury Latin School

**Keeping Balance: Adaptive Anti-Fall Control for Robots Inspired by Biomimetic Lizard Tails and Reinforcement Learning**

Changyao Hu

To address rollover risks faced by robots during high-speed movement on complex terrain, this paper, inspired by lizards and other creatures that use their tails for dynamic stabilization, proposes an adaptive balance control method based on a bionic tail and a reinforcement learning model. A bionic tail with a multi-segment rhombus linkage structure is designed in this study, and a two-rigid-body "body-tail" dynamics model is established as
the theoretical foundation of the control strategy. Using the Proximal Policy Optimization (PPO) algorithm, we trained a reinforcement learning model which takes the robot's dynamic state (pitch angle, angular velocity, acceleration, etc.) as input and outputs commands on the tail's motion. Simulation results demonstrate that the model successfully developed a control policy which conforms to basic principles of physics. Validation experiments in real life confirmed that the bionic tail system increases the robot's anti-rollover success rate to over 90% in typical hazardous scenarios such as sharp turns, emergency braking, and slope climbing. Furthermore, it effectively prevented rollovers during aerial posture adjustment tests. These experimental results fully validate the effectiveness and significant potential of combining bionic design with reinforcement learning to enhance a robot's dynamic stability.

Keywords: Robot Anti-fall Control; Bionic Tail; Reinforcement Learning; Proximal Policy Optimization; Dynamic Stability

Boston Trinity Academy

**A Fully Self-Powered Autonomous Renewable Energy System with Triboelectric-Driven Control and Theoretical Hydrogen Storage**

Jianle Gao, Angie Gomez

The intermittent nature of renewable energy sources such as solar and wind creates significant challenges for grid stability and long-duration energy storage. Hydrogen energy systems have emerged as a promising solution because they enable long-duration storage of renewable electricity and serve as a flexible energy carrier for future low-carbon energy infrastructures. However, most renewable–hydrogen systems rely on externally powered sensors and control electronics, increasing system complexity and reducing overall energy autonomy.

This project proposes and evaluates a self-powered renewable energy management system that integrates hybrid renewable generation, triboelectric environmental sensing, and hydrogen energy storage modeling.

The system combines a solar panel and micro wind turbine for renewable electricity generation, while a triboelectric nanogenerator (TENG) functions as a self-powered precipitation sensor. Mechanical energy from rain or snow impacting the TENG surface generates electrical signals that dynamically adjust the voltage threshold of the control circuit, allowing environmental conditions to directly influence energy management without external sensing power.

A low-power control circuit continuously monitors renewable input voltage and autonomously switches between operating modes. When renewable power exceeds a defined threshold, electricity is directed to an electrolyzer-equivalent load representing hydrogen production. When power falls below the threshold, the system switches to an output mode representing electricity generation from a theoretical hydrogen fuel cell.

Due to safety constraints, hydrogen production and storage are not physically implemented. Instead, hydrogen generation rate, storage capacity, and equivalent fuel cell output are quantitatively modeled using experimentally measured electrical input and literature-based electrolysis and fuel cell efficiency data. Experimental testing measures renewable electrical output and characterizes TENG sensing behavior under varying precipitation conditions. The prototype demonstrates stable autonomous switching under variable renewable inputs, while regional renewable resource data are analyzed to evaluate the system's applicability across different geographic environments.

Weston High

**A Lightweight, Durable Exoskeleton for Patients With Muscle Tremors**

Nuoyi Cao

The project is designed to use a comprehensive system of simple machines to aid in patients with upper-limb muscle tremor issues via a system that aims to use compensated and artificial motor firing patterns to counteract the excess tremors emitted by the patient.

**FluxWave: Topology-Guided Electromagnetic Induction for Distributed Wave Power**

Artiom Peshkur

Ocean waves hold enormous renewable energy, but many wave-energy devices remain bulky, mechanically complex, and difficult to scale into reliable distributed systems. FluxWave introduces a topology-guided electromagnetic generator that uses an infinity-like closed pathway to convert oscillatory motion into repeatable electrical output. The key insight is that magnetic field lines form continuous loops, so electricity is generated by repeatedly changing how those loops link through a coil, not by a single irregular pass. FluxWave enforces that repeated linkage by guiding a rolling permanent-magnet sphere along a self-crossing trajectory that returns the magnet through a compact induction throat where coupling is strongest. The system is engineered as a complete pipeline: a smooth-curvature path that preserves momentum, a localized throat that concentrates induction, and a modular 3D-printed architecture that assembles reliably while maintaining alignment and clearance. A working prototype validates end-to-end mechanical-to-electrical conversion by generating consistent voltage pulses under hand-driven excitation and illuminating an LED through rectification and load tuning. From these demonstrations, the project establishes practical design rules connecting topology (closed self-crossing loop), geometry (curvature continuity and throat placement), and manufacturing tolerances (alignment and clearance) to electrical output per footprint. FluxWave provides a scalable pathway toward buoy-mounted arrays that charge local storage and deliver regulated DC for marine sensor networks and future coastal microgrids.

Eaglebrook School

**An Elephant Trunk-Inspired Modular Variable Stiffness Soft Robot**

Max Yao

The Elephant Trunk demonstrates unique advantages in complex environments thanks to its flexibility, high degree of freedom and versatile transport characteristics. In the industrial world, it is known as nature's universal robotic arm. However, the ability to achieve three-dimensional smooth movement and stiffness adjustment similar to that of the elephant trunk puts forward higher requirements on the structural design, drive integration and functional adaptability of the robot. Here I proposed and implemented a bionic elephant trunk robotic system that incorporates a modular architecture, soft actuators, and adjustable stiffness mechanisms, with 3D motion achieved by three 120 degrees soft bellows actuators working in concert, and thus possessing continuous deformation and spatial localization capabilities. In addition, in order to cope with the demand of rigid-flexible switching for different grasping tasks, the system introduces a variable stiffness mechanism based on skeleton-particle coupling, which is capable of state adjustment and structural toughening under external loads. In the end-operation environment, the robot integrates soft suction cups with adsorption functions. This effectively improves the stability of non-regular target attachment and grasping. The system is modeled using SOLIDWORKS software and the soft actuator is constructed using 3D printing and silicone injection moulding. Experimental results show that the robot exhibits excellent adaptability, load capacity, and locomotion in multi-scenario operations. It shows its wide potential in the direction of complex environment manipulation such as service robots. Keywords: Elephant Trunk-inspired Robot; Soft Robot; Variable Stiffness; ModularDesign; Silicone Injection Molding.

North Quincy High

**Using Sustainable Energy Sources to Measure Maximum Thrust Capacity of a Model Rocket**

Rithwik Prattipati

The purpose of this experiment is to find out if an electric motor is a viable alternative to a traditional rocket motor in the rocket industry. To achieve this, the proposed design was tested in four different weather conditions. This hypothesis that was predicted was if solar panels were used as a renewable energy source for an electric motor under four weather conditions (Cloudy conditions, snow precipitation, 1-2 inches of rain and 4-5 inches of rain), then the module would perform best during cloudy conditions. A kitchen scale was used to mimic a load cell, and thrust measurements were recorded every 30 seconds to determine the overall maximum thrust capacity. The results proved that the module performed best during snow conditions with an average force rate of 0.184 N. The graphs show that although snow had the most force generated, it was not the most consistent. As to fulfill the purpose of the experiment, this module is not a viable alternative as the force exerted does not go beyond the weight of the module. This project could be relevant to aerospace engineering as this serves as a prototype of more possible electrical motorization. If this project were done again, then a larger motor, an actual load cell, and an Arduino would be used to get more accurate and precise measurements.

**High Precision Sensor Synchronization for Artistic Athletic Performance Analysis and Judging using Wearable ESP 32-Based IMU Systems**

Sophie Cao

Many artistic sports like figure skating and diving suffer from biased and inconsistent judging, because they are tasked with evaluating elements based on qualitative observation. There have been studies done to model athletic motion using wearable sensors and 3-D modeling systems, but none have put emphasis on sensor synchronization and collaboration. By developing an ESP-32 based synchronized wearable sensor system mounted on key joints of the body, people can better analyze rapid execution sports where judging or coaching by relying on sight is neither reliable nor accurate. After performing a series of simple jumping motion, the sensors were able to pick up on acceleration and rotational data to a few milliseconds of offset. This technology minimizes judging inaccuracies in artistic sports and allows athletes to set measurable targets for their training and make improvements based on quantitative data rather than feel. Moreover, by focusing on sensor synchronization, the system can be applied to many fields of motion analysis, allowing multiple sensors to collaborate in achieving an accurate picture.

Newton Country Day School

**Adaptive iPad Mount and Case for Individuals with Motor Disabilities**

Cecilia McKeigue

A common motor disability that can make iPad use difficult is a stiff involuntary muscle contraction that often results in individuals exerting more force on a surface than necessary. Therefore, when it comes to tablet use, individuals with these spastic contractions-–such as those with Cerebral Palsy (CP) who often rely on tablets as speech devices-–repeatedly knock the iPad and its stand over by involuntarily exerting too much force on the screen. The purpose of this project is to design a prop-up iPad case able to withstand applied force, friction, and torque exerted on the iPad by an individual with spastic mobility issues such as individuals with CP. After several prototypes, the pieces built for the case's construction were a wooden iPad case with an opening, a wooden back board with eight holes, eight 3D printed hooks, and the wooden "connection" piece between the case and the backboard that snapped into the hooks. The hooks were iteratively modified to ensure that the radius of the holder would be able to secure a PVC pipe that was planned to be attached to the "connection" piece (although the PVC pipe was later discarded) and that the peg part would fit into the holes in the back board. Hinges were used to put together the "connection" and the case and pieces of rubber were attached to the bottom of the back board in order to reduce friction. The sturdiness of the wooden case, the friction of the backboard, and the secureness of the hooks all ensured that the case would not move laterally for forces up to 30 N three out of five times when placed upon a rubber surface. These design features also ensured that the case would withstand the desired levels of torque when force was applied to the center of the tablet. Lastly, the  case was able to fit into a backpack of the desired dimensions and that its mass was less than 0.68 kg. The project could be improved by using a more flexible material for the case and backboard and by using thinner plastic for the hooks.

Williston Northampton School

**Gesture-Controlled Biomimetic Squid Robot Using Wearable Wristband Technology**

Yumin Cao

As ocean exploration expands into more complex and confined environments, there is increasing demand for underwater robots that are compact, agile, and easy to operate. Traditional propeller-driven vehicles can provide efficient thrust but achieving turning and station-keeping often requires multiple thrusters, which increases structural complexity and reduces flexibility in tight spaces.

To address this, this paper presents a biomimetic squid-inspired underwater robot that combines pump-driven jet propulsion with fin-assisted steering and integrates an intuitive wearable wristband controller. The robot generates forward thrust using a water-jet thruster, while servo-actuated fins produce asymmetric hydrodynamic forces for steering and stabilization. The wristband uses an ESP32 and an IMU to recognize user gestures and transmits discrete command states to the robot through a sub-GHz LoRa link for real-time control.

A modular architecture (sealed electronics compartment, fin-actuation section, and tail thruster module) supports waterproofing and maintenance, and a ballast subsystem enables basic depth adjustment. Tank experiments were conducted to verify motion functions and compare fin materials. Results show a clear trade-off between maneuverability and straight-line efficiency: softer fins provide stronger turning response, while stiffer fins improve forward efficiency and stability, supporting material selection based on mission priorities.

Keywords: biomimetic squid; wearable controller; underwater robot; gesture control; Fin actuation

Williston Northampton School

**Amphibious Spiral Pipeline Robot Equipped with Multi-sensor Monitoring System**

Hanyang Fei

With the expansion of global pipeline transportation systems, traditional manual inspection has struggled to meet the demands for high efficiency and low-cost maintenance. Addressing the severe challenges of pipeline leakage and maintenance in the United States and globally, this paper presents a small-sized, amphibious pipeline inspection robot. The core design features a pair of spiral thrusters, providing the mobility to navigate between land and water environments. It is also integrated with sensors for automated water quality monitoring and hazard detection.

Experimental results demonstrate that the design exhibits excellent navigation and accurate data collection capabilities within narrow pipelines. While there is still room for improvement regarding Bluetooth communication penetration and mass-buoyancy control, its amphibious nature offers a practical and efficient solution for pipeline monitoring. This research not only validates the potential of small-sized amphibious robots in complex pipeline networks but also lays the foundation for future optimizations in intelligent pipeline inspection technology.

Keywords☐Amphibious Robot☐pipeline Inspection☐Spiral Thrusters☐Automated Monitoring☐Hazard Detection

**Foldable Body, Unfolded Capability: Structural Properties and Functional Applications of A Novel Yoshimura Origami Tubular Robot**

Yuehan Jin

Flexible continuum robots are capable of working in confined spaces and have broad application prospects in fields such as space exploration, disaster relief, and biomedical applications. However, weight and volume constraints remain significant factors limiting their development. This project proposes a universal design method for tubular continuum robots based on the Yoshimura origami structure. Utilizing a constraint equation based on "node-side-face" elements, we obtained different design schemes for inscribed regular polygon origami robots. Based on this, we proposed an "open-window" optimization method to further enhance the compression efficiency of the Yoshimura structure. In experiments, we tested the effects of different aspect ratios and paper thicknesses on the elongation/compression ratio. The tests showed that the elongation-compression ratio of the tubular origami robot can reach 38:1. Finally, based on the inscribed regular hexagonal origami structure, we designed a magnetically driven centimeter-scale multi-segment crawling robot. These tiny robots can move independently or assemble through magnetic attraction, exhibiting efficient, multimodal motion capabilities under magnetic field driving, which can be used for drug delivery in the human body. We also designed a decimeter-scale space exploration origami robot driven by superelastic memory alloy wires. In a simulated ruin scene, it achieved flexible traversal through a multi-segment, deformable structure and collected images from the ruins through a head-mounted camera, demonstrating excellent adaptability to confined environments and potential applications in disaster relief. The research results of this project can provide a scientific paradigm for the design of lightweight and efficient origami robot structures, helping to reduce the design difficulty and simplify the manufacturing process of continuum robots.

**The Bridge Design Project**

Emery Fullin

My project was to test which of some of the most famous bridge designs could hold the most weight. I tested six different designs.MY hypothesis was that a bridge design called the Truss bridge would hold the most weight because it contains triangles which I found out during my research are one of the strongest shapes used in structural engineering. This project is necessary because it could help decide the designs for future bridges, as well as helping know which bridges are strongest and which bridges we should probably replace. For the project I built each bridge out of popsicle sticks and built then each 1 and half feet long and 4 in wide I set them up on a stack of books 1 ft apart and then tested and measured how much weight each held then recorded and analyzed my findings, I found that the Cantilever bridge held the most weight by holding 11,339 g followed by the Arch bridge with 4,057 g then the Truss bridge with 4,044 g then the Tied Arch bridge with 3,553 g, the Beam bridge with 2,267 g and finally the Cables Stayed bridge with 425 g. Though my hypothesis was unsupported, the Cantilever held the most weight while I had said that the Truss bridge would hold the most weight. Some of my thinking was correct because the bridge with that held the most weight was made up of triangles.

**Designing An Alternative Energy Source That Is Cost Efficient**

Adedipo Soyele

This project investigates how to design a cost efficient alternative energy source that's useful in emergencies by creating homemade batteries inspired from common household materials. This project was influenced by personal realization as to how electricity can often be taken for granted, as well as the need to reduce the pollution and resource depletion caused by traditional batteries. By applying the principles of redox reactions and Alessandro Volta's voltaic pile, the project tested combinations of copper pennies, zinc washers, and different electrolyte solutions, to see how such combinations influence voltage output and battery lifespan. Initial testing revealed that a mixture of lemon juice and vinegar was the most effective solute, yielding approximately 1.1 volts per cell. To create a practical alternative battery, a 5 cell battery was integrated into a 3D printed cylindrical casing designed using Fusion 360. This prototype produced 6.2 volts, successfully exceeding the target goal of 5 volts and powering an LED strobe light. Performance testing established a reliable linear model for voltage decay with under 5% error, while cost analysis proved the design's economic viability at just $0.16 per cell. Although the project met all success criteria, including a duration of over 15 minutes, future plans for this project includes improved wiring to connect with devices, and more secure casing mechanisms to enhance contact with the battery for connected devices. Ultimately, this project demonstrates that accessible, everyday materials can provide sustainable low-power energy solutions for emergency and reliable use.

Tabor Academy

**Design of Passive and Actively Transmitted Elastic Structures for Humanoid Robotic Limbs**

Yuxi Zhou

Humanoid robots are typically constructed using rigid metal structures with motors directly connected to joints. While this architecture provides strength and precise control, it lacks a compliant intermediate layer similar to human muscle. In biological systems, muscles deform and redistribute forces during motion, reducing peak loads on joints and enabling smoother interaction with the environment. As humanoid robots become more involved in human-centered environments, incorporating compliant structures may improve safety and mechanical adaptability.

This project investigates whether elastomeric lattice structures can function as a muscle-like intermediate layer in robotic hands. Parametric Voronoi lattice geometries were designed using Rhino and Grasshopper and integrated into a robotic finger prototype. Testing focused on a single finger as a simplified model of the hand, since grasping forces in robotic systems are primarily concentrated at the fingers. The structures were fabricated using elastomeric resin through stereolithography (SLA) 3D printing. Two elastomer materials with different stiffness levels, ELASTO1000 and ELASTO3000, were mechanically characterized using a universal testing machine through tensile and compression testing to evaluate stress–strain behavior, stiffness, and load-bearing capacity.

Results showed that ELASTO3000 exhibited a higher elastic modulus and greater compressive force capacity, indicating higher stiffness, while ELASTO1000 demonstrated greater compliance and deformation under loading. Because of its flexibility, ELASTO1000 was selected for integration into a tendon-driven robotic finger actuated by a servo motor. The prototype demonstrated controlled bending and repeatable deformation of the lattice structure during actuation.

These results suggest that elastomeric lattice architectures can act as compliant mechanical intermediates that both transmit forces and enable controlled deformation. This approach may contribute to the development of safer and more adaptable humanoid robotic hands.

Newton North High

**Evaluating the Durability of Artemia Cyst-inspired Composite Architecture**

Alyssa Yasuhara

Aerospace laminated composite materials are composed of fiber-reinforced laminates with resin matrices to optimize the strength-weight ratio, durability against fatigue, temperature, and load or stress. Similarly in nature, laminated structures like Artemia cysts consist of an asymmetric laminate stacking sequence to minimize mechanical damage and sustain biological advantages. This study investigates how the differing layering sequence of carbon fiber and fiberglass within a hybrid composite will affect the time-dependent deformation and failure modes under a constant load. The laminates were fabricated in a polyester resin matrix with three varying layers of C (carbon fiber) and F (fiberglass); for example, the following 6 configurations were used within the study: CFC, FCF, CFF, FFC, CCF, FCC. These samples were tested on a three-point bending test where a load was applied in the center. The deflection curve, failure modes, and delamination were recorded in relation to time. Results showed an overall longer duration before total failure for samples with carbon fiber outer layers, while those with fiberglass outer layers had a shorter duration. Within the 6 sample variations, even those that used the same materials, depending on the layering order, the failure time, deflection, and deformation behavior were altered. Time of delamination was measured, and results found the time of failure since delamination varied by 10<x<120 seconds after delamination, resulting in a progressive failure instead of a catastrophic failure. A 6-group multiple comparison through one-way ANOVA with Turkey comparison was used to analyze the values, which were found to approach statistical significance, suggesting a possible trend for differences between samples. Groups such as CFF & FFC or FCC & CCF show trends that suggest differences in mechanical behavior due to varying stacking order. This provides insight into how Artemia's asymmetrical laminating sequences contribute to the tolerance of external stress, while allowing internal forces to hatch the cyst. Thus, the analyses show that variation in sequence order significantly changes the mechanical properties of a laminate, and how delamination can potentially act as a damage tolerance, explaining the approach to why successful extromophiles like the Artemia utilize specific laminate sequences in their cysts.

Keywords: fiber-reinforced laminates, Artemia cyst, delamination, three-point bending test

**Inverse Filtration of RIRs Identified by Adaptive Filters**

Mahnaz Ronan

When a signal excites a room space, the room responds with reflections, the room impulse response (RIR), and may distort or dampen the spectra. Adaptive finite impulse response (FIR) filters are utilized within digital signal processing (DSP), but the LMS, AP, and RLS algorithms benefit from data regarding deconvolution capabilities. The purpose of this project was to contribute experimental evidence to inverse filtering involving adaptive filters. If three adaptive filters converged to a similar and minimal error for sine wave signals, then the other highly correlated signals with broadband excitation would cause unstable convergence by the RLS, convergence to optimal errors by the AP, and convergence with larger error margins by the LMS algorithm. Source tracks were played in a room, recorded by a microphone. These signals were processed by adaptive filters, and the RIR was assumed by minimizing the error between the source audio and recorded. The IRs were inverted and Tikhonov-regularized—then, convolved with the reverberant signals. The AP algorithm exhibited computational time increases compared to the LMS algorithm, but its data-recycling led to well-fitted RIRs. Inversely, the LMS algorithm ran faster, but produced larger errors and struggled to resolve fine temporal details. The RLS algorithm diverged due to non-regularization and having low levels of data-reuse. While long IR identification, where computational cost inflates, is best executed in the frequency-domain, the time-domain filtration of highly correlated signals was best computed with the AP algorithm, while for narrowband estimations of the RIR, the LMS algorithm was preferable for computational simplicity.

**Electronic Nose for Pheromone Detection of Plutella Xylostella using a Custom Machine Learning Model**

Rishabh Mathukiya, Aditya Naravane

The Diamondback Moth, scientifically known as Plutella Xylostella, is a globally harmful invasive species, causing tremendous economic losses in the realm of agriculture and farming. The Plutella Xylostella is commonly present in fields containing cruciferous crops, such as cabbage and broccoli, which are frequently consumed and grown crops worldwide. Due to its rapid reproduction rates, the moth can develop and build resistance to pesticides fairly quickly, resulting in new investigations into how to mitigate and manage the population using new variants of pesticides. Early detection of its pheromones can help monitor the species population and improve integrated pest management (IPM) capabilities. This work presents the development of a low-cost Electronic Nose (eNose) system equipped with an array of localized sensors to detect pheromone-related volatile organic compounds (VOCs). The system integrates a custom Machine Learning model, which is trained to obtain the input from the sensors, process the input, and output the likelihood of the presence of the Plutella Xylostella pheromone. The sensor responses were recorded in real-time and analyzed for standard inputs to train the model. This work lays the foundation for future development of autonomous methodologies for early invasive species detection using their pheromones, helping build agriculture and environmental resilience and sustainability.

**Kinetic Energy Harvester to Power Small Devices**

Pahlaj Sharma

Wearable electronics are limited by a power gap requiring frequent charging. This project engineered a low-cost shoe insole to harvest kinetic energy from human gait using a piezoelectric array. A prototype was constructed by tracing an athletic insole onto a polycarbonate sheet to create a rigid foundation for maximum transducer deformation. Seven piezoelectric discs were wired in a parallel star topology to minimize impedance and connected to an MB10S bridge rectifier to convert AC pulses into DC.

Energy was stored in a 1.0F supercapacitor. Results from five trials of 100 steps each demonstrated high reliability with a standard deviation of 5.09. The harvester achieved an average net gain of 80.2 mV per trial and an efficiency score of 22.30%. Data identified the heel (4.2V) and ball of the foot (3.8V) as the optimal anatomical pressure zones. Testing revealed that concrete yielded the highest output, while soft grass reduced efficiency by nearly 30%. This research confirms that a parallel-wired piezoelectric array can reliably transform walking gait into a functional power source.

**From Material to Intelligence: Using Conductive Hydrogels as Smart Skin for Robotic Devices**

William Zhang

This project explores the feasibility of using conductive hydrogels as smart artificial skin for prosthetics or humanoid robots. Two different types of conductive hydrogels, the PVA-Carboxymethyl Chitosan Network (PCCN) hydrogel and the guar-gum-borax network (GGBN) hydrogel, have been developed and their conductivity has been characterized.

The introduction of NaCl and freeze-thaw cycles imposed excellent conductivity for the PCCN hydrogel, however, the prepared hydrogel shows insufficient gelation, and its low modulus leads to challenges in being used as artificial skin for robotic devices. The GGBN hydrogel shows excellent strain strength, flexibility, and self-healing properties, as well as extraordinary conductivity from the introduction of NaCl, making it a great candidate as the artificial skin for robotic devices.

The GGBN conductive hydrogel has been integrated with a robotic hand, and the sensorimotor performance has been evaluated by grabbing and releasing 4 different objects. The results indicate that conductive hydrogels, like skin, can generate different electric signals based on the robotic finger movement and the grabbed objects.
Additionally, using the electrical signal changes from 26 grabbing and releasing tests for each of the 4 objects, a Random Forest Model was trained to match the signal changes with the object grabbed, exhibiting a success rate of around 90.5%. These findings will help pave a new path in the field of robotics as conductive hydrogels could serve as a new type of smart artificial skin for robots and bionic devices.

Shrewsbury Sr High

**Aerodynamic Optimization of a Bio-Inspired Autorotating Airdrop System: Reducing Landing Error and Impact Velocity**

Vaibhav Vinodhkumar

For the past two decades, the aerospace industry has faced a critical trade-off between cost-efficiency, landing precision, and impact velocity, relying heavily on standard circular parachutes that suffer from drift and dangerous impact velocities. While precision-guided systems have been developed to mitigate these failures, their prohibitive cost limits widespread adoption for humanitarian, logistical, and delivery missions. This project aimed to improve upon the most commonly used circular parachutes by developing a passive, bio-inspired descent mechanism that leverages samara seed autorotation to enhance accuracy without relying on high-cost GPS precision systems. Following Computational Fluid Dynamics simulations that demonstrated the feasibility of the idea, four iterations of Samara Descent Systems were fabricated and subjected to 50 controlled drops each, where impact velocity and landing error were measured against the circular parachute (control). The optimized design, Prototype 4, achieved a 53% reduction in mean landing error and a 32% reduction in impact velocity, with high statistical significance ($p < 0.001$), while using the material polycarbonate. After testing under 10 and 20 mph crosswind, upwind, and downwind conditions dynamic similarity calculations suggest aerodynamic feasibility preserved at larger scales. These results indicate a promising low-cost alternative to expensive electronics-guided descent systems for affordable and high-precision. Future research will consider experimentation in large-scale wind tunnels and increasing payload weight capacity.

**Piezoelectric Energy Harvesting for Next-Generation Aircraft Systems**

Puneeth Nunna

For over two decades, the aviation sector has sought lightweight, passive methods to recover energy from aerodynamic loads and reduce carbon emissions. Current gaps include limited experimentation with the implementation of piezoelectricity and the placement of the sensors, which could include systems of sensors integrated at a mix of high-dynamic pressure regions on the wings of aircraft. The role of the angle-of-attack (AoA) in mediating those effects is also an important aspect in consideration. Therefore, this study systematically compares electrical output by piezoelectric (PZT) ceramic disk sensors at three wing locations: 50%, 75% , and 100% (measured from the root to the tip of the winglet), to capture vibrations. Using computer-aided design (CAD) software, a 3D-printed wing model with piezo sensors attached at different positions underwent wind-tunnel tests that were performed across three different AoAs: -10°, 0°, 10°, to vary vortex strength and vibration intensity. Measurements included voltage production, read from a multimeter, and drag production, read from the wind tunnel. Wing geometry and sensor orientation and type were held constant to reduce variability. Through two-sided Welch t-tests ($\alpha = 0.05$), results show sensors mounted at 50% placement (specifically cruising altitude where aircraft spend most of their time) have greater electrical output than 75% ($p = 0.0018$) and 100% placements ($p < 0.001$) at 0° AoA, though the statistically significant drag penalty relative to baseline and other placements ($p < 0.001$) makes it optimal only when accepting that tradeoff. Thus placement selection depends on mission priorities: maximize power or minimize drag. This proof-of-concept demonstrates that targeted piezoelectric placement can recover useful energy for onboard sensors and low-power electronics in not only avionics, but with optimization, it can be adapted for other fields such as automotive and marine industries.

Belmont High

**Carbon Quantum Dot-Integrated Nanocomposite Dielectrics for Enhanced Capacitor Performance**

Ray Xue

Meeting the growing demand for energy storage with high efficiency and environmental compatibility, this study examines the possibility of using carbon quantum dots (CQDs) in nanostructured dielectric materials. CQDs were tested as both a standalone material and a constituent in composites with graphene oxide (GO), titanium dioxide (TiO2), and aluminum oxide (Al2O3). Capacitance and dielectric constants were calculated by performing an AC impedance spectroscopy (EIS) on capacitors with aluminum electrodes, sodium sulfate (Na2SO4) electrolyte, and a PFSA (Nafion 117) membrane separator; frequencies exhibiting capacitive-dominant angle ranges were analyzed. Results demonstrated that CQD integration significantly altered dielectric behavior depending on the host material. The CQD-Al2O3 composite showed the highest stable dielectric constant (κ ≈ 21.464), representing substantial improvement over both CQDs (κ ≈ 6.842–8.146) and Al2O3 (κ ≈ 11.517) alone, with a concurrent reduction in resistance. The CQD-GO composite also achieved notable improvement (κ ≈ 9.046□13.647) but exhibited device-to-device inconsistency attributed to dispersion and mixing challenges. In GO-based devices, extreme dielectric peaks (κ ≈ 872.168) and short-circuits were observed, consistent with Maxwell-Wagner polarization (MWS) and film defects. For TiO2, CQD incorporation produced stable permittivity improvements (κ ≈ 4.616□8.368) in well behaved devices, though some samples show high spikes (κ up to ≈ 50.038) due to instability and agglomeration, limiting reliability. Overall, CQD integration tends to improve both the dielectric constant and reduce resistance in several composite systems, with the strongest and most reliable results attained in CQD-Al2O3 systems. These results indicate that CQD-integration in dielectric nanocomposites has great potential for future dielectric applications in energy storage technologies.

**Inflatable Soft Wearable Knee Joint Rehabilitation Device**

Yinhong Qian

Knee injuries and osteoarthritis affect over 654 million people worldwide, yet most rehabilitation devices are either bulky, expensive, or fail to adapt to the natural movement of the joint. This project presents a soft, inflatable wearable knee rehabilitation device designed to make recovery more accessible, comfortable, and effective for adults aged 18–70.

The device combines a curved TPU-nylon airbag with a motorized cable-drive system, creating a dual-drive mechanism that delivers smooth, stable assistance across the full range of knee motion. A built-in Mediapipe-based computer vision module estimates real-time knee angle, while pressure and tension sensors continuously monitor performance—enabling precise, adaptive control with an angle error below 3°, tension error below 10%, and an emergency stop response within 0.1 seconds.

Three rehabilitation modes are supported: Passive mode guides the leg through motion for patients with limited muscle control; Active mode provides supplemental assistance during voluntary movement; and Resistive mode builds strength by applying controlled opposition. The device is built on a standard knee pad for comfort and portability, making it suitable for both clinical and home use.

Validation involves adult volunteers performing baseline and assisted 10-meter walks, with performance evaluated across safety, comfort, motion accuracy, and completion time.

By integrating soft robotics, real-time sensing, and adaptive control into a lightweight wearable, this project offers a practical and patient-friendly step forward in accessible knee rehabilitation technology.

Keywords: Inflatable wearable knee, Rehabilitation device, Soft robotics, Dual actuation, Knee assistive

**Self-Assembling Modular Robots Enabled by an Articulated Multi-Axis Connector**

Chenghao Xu

Massachusetts Academy of Math & Science at WPI

**Improving Airfoil Efficiency Using Deployable Vortex Generators with Surrogate-Based Control**

Ishan Kasam

Vortex generators (VGs) energize the boundary layer to delay flow separation, preventing stall at high angles of attack, but their fixed height imposes continuous parasitic drag during cruise — a persistent penalty for UAVs and light aircraft at Reynolds numbers of 0.8×10☐ to 2.0×10☐. Existing deployable VG systems address this partially, but rely on binary deploy/retract logic rather than continuous height optimization. This work presents a surrogate-based control framework that predicts aerodynamic coefficients at any VG height to select the optimal configuration at each flight condition. A dataset of 154 medium-fidelity RANS simulations spanning angle of attack, Reynolds number, and VG height was generated for a NACA 4415 airfoil, then corrected by 10 high-fidelity URANS simulations through a residual multi-fidelity approach, achieving high-fidelity accuracy at a fraction of the computational cost. A Gaussian Process Regression surrogate was trained on this dataset, selected for its native uncertainty quantification, which allows the control algorithm to make reliable height decisions across untested conditions. The surrogate achieved $R^2 > 0.9995$ for both lift and drag prediction. In a mission simulation, the adaptive system outperformed all fixed-height VG configurations, improving mission-averaged lift-to-drag ratio by 6.5% and saving 2.66% fuel over the nearest fixed-height baseline, with VGs retracted for 97.9% of the mission. These results establish that continuous VG height optimization via multi-fidelity surrogate modeling is a viable and effective alternative to binary flow control strategies for small aircraft.

Andover High

**Printing 2D MXene-Based Chipless Radio Frequency Identification Tags to Enable Plastic Waste Sorting for Recycling**

Kevin Sun

Plastic recycling is limited by mis-sorting across polymer families and additives. Current identification methods, such as SPI resin codes, labels, and visible/near-infrared/Fourier Transform infrared (VIS/NIR/FTIR) sorting, often fail for dark or filled plastics, multilayer materials, and contaminated packaging. We introduce a printable, chipless radio frequency identification (RFID) tag based on high-conductivity MXene traces protected by an ultrathin polyvinyl alcohol (PVA) film. The tag provides robust, remote identification, yet detaches/disperses in the standard alkaline, elevated-temperature wash already used in recycling processing, preventing contaminant carryover. We engineer resonant geometries for RFID readability, quantify oxidation-limited drift, and show that an ultrathin PVA film slows oxygen ingress to preserve conductivity and read range over storage and use. In simulated wash lines (1–2% NaOH, 60–85 °C), both MXene and PVA dissolve rapidly, yielding effective removal and negligible residue on flakes. This approach enables accurate pre-recycling sortation without compromising downstream polymer quality, offering a practical path to efficient and higher-purity recycled streams.

Phillips Academy

**Liquid-metal Electronic Skin Helps Modular Continuum Robot Realizing Self-sensing**

Youran Zhang

Compared to traditional rigid robots, soft continuum robots offer superior environmental adaptability and have been widely applied in target manipulation, pipeline inspection, rescue operations, and medical surgeries. However, the lack of proprioception in soft robots makes it difficult to achieve precise shape control and motion planning in complex environments, often leading to open-loop drift under load. Furthermore, the mechanical mismatch between rigid industrial sensors and flexible materials has hindered the integration of effective sensing systems. To address this critical gap, this paper proposes a stretchable, camera-free proprioception system using a liquid-metal-based electronic skin (e-skin). Inspired by biological pro-prioception, the system maps the skin–nerve–brain pathway onto a soft robot. The e-skin comprises three liquid-metal strain sensors screen-printed on a thermoplastic polyurethane (TPU) film, which wraps conformally around the robot body. A physical model is established for real-time 3D shape reconstruction using the constant curvature assumption and resistive strain mapping. Experimental results demonstrate that the liquid-metal strain sensor achieves excellent linearity (R2 > 0.99) with a sensitivity of approximately 0.58 Ω/mm. The sensor-predicted coordinates achieve sub-centimeter accuracy across all three axes, with less than 5 mm error at 100 Hz, costing under $50. This work proves that biological design principles can directly translate into engineering solutions, enabling occlusion-free shape sensing for soft continuum robots in diverse applications.

Index Terms—Liquid metal, e-skin, strain sensor, modular soft robot, proprioception, continuum robot.

Billerica Memorial High School

**Electric Eel-Inspired Batteries For Implantable Medical Devices**

Sophie Barriault

Many implantable medical device users rely heavily on said devices, from things like insulin pumps to pacemakers, meaning that they should spend as little time as possible without their device's usage. However, because many of these devices are electrically powered, many a time the battery of these devices has to be replaced, which in some cases can result in risky surgeries. While these surgeries don't have to be performed often, only every couple of years, being without these life-saving devices can still pose risks to patients' health. In order to solve this issue, this project aims towards the development of an electric eel-inspired battery designed as a better alternative for implantable medical devices batteries, in order to eliminate the need for periods where users are without their devices. In order to do so, the battery will be built with various cells of stacked hydrogel plates, that mimic the electricity-generating specialized cells found in electric eels called electrocytes, and will use an ion gradient found within the artificial electrocyte, hydrogel stacks in order to generate electricity, similarly to how electric eels do.
Keywords: Chemistry, electrochemistry, engineering, electrical engineering, biomedical engineering, physics, medical apparatus, medicine, biology

Marblehead High

**Biomimetic Ornithopter Modeled on Dragonfly Flight**

Filip Wabno, Mark Matusik

Aerial monitoring platforms typically cost $5,000-$50,000 per unit, making distributed deployment unrealistic, while custom firmware remains a major expertise barrier to lower-cost application-specific aerial platforms. We asked whether flapping-wing mechanics could be designed so that an unmodified quadcopter flight controller could stabilize the vehicle with no firmware changes - a property we call mechanical control equivalence. We built an 8-wing ornithopter in which four synchronized wing pairs replaced the four rotors of a quadcopter, while preserving the controller's assumptions for monotonic thrust, differential yaw, and symmetry about the center of mass. The system ran stock Betaflight on a commodity flight controller and had a total flight mass of 52 g. On a precision scale rig, we measured 16 gf steady-state thrust per wing pair (3 trials, standard deviation reported). Combined thrust through the full electronics path was approximately 55 gf (T/W approximately 1.05), sufficient for stable tethered hover. The 9 gf deficit relative to the ideal sum was traced to electrical voltage sag (1.1 V drop across board, connectors, and wiring with four motors active), while aerodynamic interference was ruled out by bench-supply testing at fixed 4.5 V. Yaw response on a low-friction swivel was 9.8 deg/s at 20% diagonal differential (3-trial mean). Total bill of materials was under $172.54 (vehicle only). To our knowledge, this is the first flapping-wing hover platform designed explicitly for compatibility with an unmodified commodity quadcopter controller through mechanical control equivalence.

**Development of a Modular Biomimetic Spinal Snow Rescue Robot**

Boran Jayden Zhao

In extreme snow rescue scenarios, traditional wheeled and tracked robots are often restricted by insufficient snow friction, pitch instability, and weak climbing ability. Mature tracked chassis, due to the large size of the dual-track structure, cannot pass through narrow terrain. Existing modular designs mostly focus on overall size adjustment, lacking standardized docking schemes for flexible skeletons, and commonly used industrial interfaces have insufficient convenience in emergency splicing and adaptive control capabilities, failing to meet the core demand of "rapid deployment and flexible combination". Addressing these pain points, this study focuses on two core directions: first, designing an integrated "mechanical + electrical" standardized docking scheme with a "dovetail groove + bolt" composite interface to realize rapid module assembly/disassembly and stable connection in snow scenarios; second, optimizing the TPU flexible joint structure to improve traction on complex roads while retaining lateral flexion degrees of freedom. PETG shells and track modules are fabricated via SolidWorks modeling and 3D printing, combined with non-equidistant drive gears and closed drive slots for robot assembly. Performance is verified through 60/120/180mm gully tests and soft ground passability tests, with data processed by the moving average method. The robot can be flexibly combined into long-span monorail and other forms to meet the rapid deployment needs of snow rescue, while providing a technical framework for the modular design of flexible robots and extending to multi-scenarios such as urban ruins detection.

Grafton High School

**Improving Accelerative Efficiency of Solar Sails**

Kavin Adhav Sivadhaya, Joseph Cordero

This project aims to improve solar sail accelerative efficiency by increasing flatness and hybridizing source of thrust. To increase flatness of the sail, shape memory alloys will be implemented to eliminate creasing, bowing, and wrinkling, which all inhibit optimal performance. In addition to this, the implementation of an electric solar sail will harness a previously untapped source of thrust by accessing the momentum of ionized particles in the solar wind, further increasing accelerative potential.

**Optimization of a Low-Cost Prosthetic Hand**

Lokesh Katra, Krishiv Jayaswal, Ritesh Kumar Tondepu

Millions of people around the world cannot afford advanced prosthetic limbs. Existing prosthetics can cost tens of thousands of dollars, making them inaccessible to many individuals. Additionally, these devices often require complex sensors and calibration systems that further increase cost. Our project is about creating a prosthetic hand which is a prototype that is controlled by hand gestures seen through a webcam. We aim to reduce the cost of producing a prosthetic hand which keeps its functionality.

**Using Sound Wave Frequency to Predict Avocado Ripeness and Reduce Food Waste**

Alana Came, Andrei Grudkowski

Avocados are often thrown away due to a miscalculation about their ripeness, causing unnecessary food waste. The purpose of this project was to figure out whether sound wave frequency patterns could be used to accurately predict avocado ripeness without having to squeeze it or cut it open. We hypothesized that unripe avocados, which are firmer, would produce higher amplitude frequency spikes when tapped compared to overripe avocados, which are softer. To test this, we engineered a device using many materials, including a elegoo uno r3 Arduino, solenoid, piezo vibration sensor, and MOSFET, which is set on a foam board "table". The solenoid was programmed to gently tap/punch the avocado, and vibration data collected by the piezo sensor was analyzed using the SciStatCalc FFT calculator. We did multiple trials (at least ten per avocado) on both unripe and overripe avocados while trying our best to keep the orientation and distance consistent. Results were analyzed using FFT frequency graphs. We found that unripe avocados produced consistently high amplitude spikes. On the other hand, we found that overripe avocados produced lower and less consistent spikes. Although some of the trials showed strange graphs, probably due to experimental errors, we did get data that supported our hypothesis. Our project demonstrated that sound-wave analysis does have the ability to provide accurate information about avocado ripeness. Future improvements include using a different software to get exact values for frequency peaks for more precise ripeness predictions, testing on a much larger sample size of avocados, and testing in a better environment that would have less of a negative impact on our testing. We hope that this method could be used to reduce food waste in homes and stores by identifying fruit at the right stage, making both people and the environment happy!

**The Power of the Perfect Angle**

Shahed Alrashid

This project focused on understanding and experimenting with solar panels. The main goal was to determine which angle would cause a solar panel to produce the most energy, while also using barriers to imitate human use of that energy, called resistors. Additionally, two different solar panels were tested –a 10 W panel and a 20 W panel– to see if the panel size affected the results in any way. Solar energy is one of the most important renewable energy sources in the world today. To determine the power a solar panel is able to produce, we need to find out two main components: voltage and current. Those two components are multiplied to find the power that the solar panel makes. The efficiency that the solar panels produced under different angles and resistance conditions were also calculated in order to see how much of the solar panel's maximum power was being used. This process was repeated for more accurate results. The results showed that a 15-degree angle produced the highest energy compared to the other angles that were tested. The resistance, on the other hand, had to be a medium-load resistor because if it was too low, it would cause too much current flow, and if it was too high, it would interrupt the current flow. These results not only show us which circumstances the solar panel should be in order to produce the most energy, but they also help us to understand how small differences can make a bigger effect in the long run.

Everett High

**Accessible Wheelchair Entrance to Public Buildings**

Ali Raza, Lucas Martins, Elvis Nguyen

Of all people with disabilities that have mobility impairments, only 23% feel they are fairly accommodated, according to PR Newswire. Despite updated ADA standards from 2002, public transportation's challenges with vague accessibility definitions and unreliable support still remain. One of these major issues is curb inaccessibility, as according to the National League of Cities, 48% of sidewalks and 65% of curb ramps in the United States are not entirely accessible. Most solutions to curb inaccessibility that were researched came in the form of ramps. The ramps had many marketable features, such as being foldable, lightweight, retracting, anti-slip, and 'portable'. However, these solutions are all meant to be deployed by a caretaker, and not a person who uses a wheelchair, which is problematic because wheelchair users can become helpless in the event that there is no one around to help them and getting on the sidewalk is not possible by themselves. After conducting profuse research on sciencedirect.com, jstor.org, and other sites using keywords like "curb inaccessibility", "wheelchair inaccessibility", etc., our team was able to extract important information including statistically significant evidence proving that curb ramps often violate the 1:12 ratio set by the ADA. Furthermore, our team looked for instances where failure to comply with ADA standards led to injuries and the evaluation of wheelchair accessibility from the perspective of wheelchair users themselves. This allowed our team to brainstorm our own solutions and create the specifications for our decision matrix. Our team decided to use two linear actuators stationed at the wheels that, when the user does a wheelie and gets the caster wheels on the curb, they activate the linear actuator which pushes them up. The purpose of the linear actuator is to apply a pushing force on the ground to lift the wheelchair. We also 3D printed a holder with a wheel on the bottom where the linear actuator would go that allows the user to move forward when the linear actuator pushes down. Upon testing our prototype for functionality with different weights, for different elevations, and human independence, one male team member of average weight (63 kg) stationed themself in front of a curb. Then, they did a wheelie on the back wheels and once the caster wheels (small front wheels) were on the curb, they pressed a button to activate the linear actuators that push down on the ground, lifting them up. They pushed forward and were successfully able to make it to the curb. However, upon retrying with a heavier team member (90 kg), the linear actuators struggled to push with enough force, causing a failed attempt.

Acton-Boxborough Regional High

**BioBeacon: A Low-Cost, Insect-Inspired, Stigmergic Swarm of Sensorized Robots for Accelerated Autonomous Disaster Response**

Anirudh Pulugurtha

Every year, over 50,000 people worldwide die as a result of natural disasters; human search-and-rescue missions are often dangerous, while existing robotic disaster-relief systems are costly and difficult to deploy at scale. Many current robotic solutions are limited by their large size, high weight, and expense, which reduce maneuverability and accessibility, and by their lack of inter-robot communication. BioBeacon addresses these limitations by providing a low-cost, small-scale, and cooperative autonomous disaster-relief system; inspired by insect stigmergy, where organisms leave environmental "traces" to communicate information, BioBeacon integrates object, positional, and gas sensing to enable intelligent coordination. The system consists of a swarm of custom-designed ESP32-based robots that collaboratively search for and locate target objects. Experimental results show that BioBeacon significantly outperforms single-robot configurations, by about 26%, in both the speed and reliability of object detection and convergence.

B M C Durfee High

**SelfHealingCognitiveRadioForRemoteAreas: The Utilization of Decision Tree ML to Have a LoRa Network Self Adjust Its Power Usage**

Robert Medrano

This project seeks to solve the issue of data loss/data retention for applications such as weather stations and disaster early warning systems in post natural disaster society. The solution will involve the use of Cognitive Radio (CR) on an Field Programmable Gate Array (FPGA) being tested in various conditions with Software Defined Radio (SDR) and Random Forest (RF) in order to establish reliable, rugged, and efficient Disaster Relief Sensor Networks (DRSNs). The methodology used to evaluate will be quantitative data comparison between standard sensor network systems under pressure versus the aforementioned DRSN. The goal is to provide a substantial increase in date retention, data gathering speed, and prevent data loss overall especially for local researchers in developing areas post natural disaster.

Falmouth Academy

**Is CO2 Electrochemical Reduction a Solution for the Future?**

Alden Bank, Ari Aretxabaleta

One way to reduce atmospheric CO2 concentration is electrochemical reduction, which converts CO2 into a usable compound. The goal of this project was to convert CO2 into ethanol through electrolysis, fermentation, distillation, and saponification, and determine if a large scale version is a possible solution for the future. An electrolyzer was designed and built to perform electrolysis on CO2 and water, creating syngas. An anaerobic bacterium, Clostridium ljungdahlii, fermented the syngas into ethyl acetate. Bacterial cultures were recharged twice daily with syngas for five days and were observed under a microscope to measure growth. The ethyl acetate was distilled from the medium, then saponified by adding sodium hydroxide and stirring to induce a chemical reaction producing ethanol. Another distillation then separated the ethanol. Syngas was successfully created, as CO and CO2 were detected in substantial quantities, and no oxygen was detected. The bacteria were kept in an anaerobic environment and increased in population. Ethyl acetate was detected using a smell test. One drop of the distillate remained liquid when placed in a freezer, indicating that it was likely either ethanol or, if the saponification failed, ethyl acetate. Whether the CO2 was converted to ethanol, the desired product, or ethyl acetate, it became a usable substance from what would otherwise be a harmful greenhouse gas. Overall, the engineering goal was achieved in small quantities, a promising result for performing the same process on a larger scale.

St. John Paul II High School

**Reducing Water Use in AI Data Center Cooling: A PCM□Buffered Hybrid Evaporative System with Condensate Recovery**

Grace Egmore

As AI continues to develop, so does the need for innovative cooling solutions for data centers. Many current cooling technologies are environmentally harmful, so I built and tested a hybrid evaporative cooling system designed to reduce energy and water waste. The system combined an evaporative pad, a condensate□recovery loop, and a PCM thermal buffer under Arduino control, allowing the pump to run only when needed. A controlled resistive heater simulated a server heat load while the rig operated in three modes: (A) fan only, (B) continuous evaporative cooling (pump always on), and (C) hybrid (pump enabled only when the PCM was melted or the simulated server temperature rose). I measured water lost and recovered, logged electrical energy, and computed L/kWh (net liters lost per kWh of cooling) for each mode. Temperature and humidity were recorded to evaluate thermal performance and ambient effects. Results showed the hybrid mode reduced L/kWh relative to continuous wetting while maintaining comparable temperature control; the simulated server stayed within ±2°C of the setpoint for a larger fraction of run time in hybrid runs. PCM buffering smoothed temperature spikes and lowered pump duty cycle, and condensate recovery returned measurable volume to the reservoir. Overall, the hybrid approach demonstrated improved water efficiency per unit cooling without sacrificing thermal performance.

Tabor Academy

**Composite Modular Power Generation System for Extending the Endurance of Underwater ROVs**

Shichen Wei

This study designed and built a composite modular offshore power generation system that integrates wave energy, solar energy, and moisture-enabled generation technologies on a single floating platform. The objective is to extend the operational endurance of underwater remotely operated vehicles through this portable and easily deployable modular system. Inspired by the morphological structure of jellyfish, the prototype underwent three major design iterations and multiple minor adjustments. The final prototype employs a central buoy and six double-rocker mechanisms to harvest wave energy, where the mechanisms convert the oscillatory motion of floating plates into bidirectional rotation to drive motors for electricity generation. The six generators provide a combined power output of 30W. Four polycrystalline solar panels are flush-mounted on each floating plate, with a total of 24 solar panels delivering 14.4W of power generation. Additionally, 168 flexible moisture-enabled generation films are attached to the undersides of the floating plates, utilizing a poly(γ-glutamic acid)-based hydrogel that generates electricity through moisture-induced proton gradient formation, collectively providing 15.1μW of power output. A unified power dispatch system employing bridge rectifiers, smoothing capacitors, and DC-DC boost converters integrates the three energy sources into a stable 24V DC output suitable for ROV battery systems, achieving approximately 45W of total regulated power. The central buoy's mechanical design successfully eliminates the need for seabed anchoring while enabling easy folding for portability, achieving convenient deployment and recovery transportation characteristics well-suited for temporary maritime operations such as ROV missions. Through theoretical calculations and preliminary experimental validation, a single prototype of this system can extend ROV endurance by 20-30%. This work establishes a foundational framework for future development towards autonomous, long-endurance underwater robotic operations.

Amherst Regional High

**MOPP: Mosquito and Organism Purification Project**

Maxwell Costa, Yatharth Rajakumar

Open stormwater drains often accumulate stagnant, nutrient☐rich water that supports algal growth and creates suitable habitats for mosquito larvae, increasing the risk of vector-borne disease transmission. This study investigates whether low☐voltage electroflotation, a process in which microbubble generation lifts suspended particles, can reduce algal turbidity in a controlled labratory environment. Experiments were conducted using Chlorella vulgaris in ½☐gallon jars with graphite electrodes spaced 0.75 cm apart and powered by a bench supply at 0V, 5V, 7.2V, and 10V. The system ran for 5 minutes every 2 hours using a proprietary MOSFET-based timing circuit. Turbidity was measured at the surface and mid-depth at 0, 1, and 24 hours. Results showed that 7.2 V consistently produced the strongest clarification, reducing turbidity to below 0.1 NTU while avoiding the excessive foaming and pigment damage observed at 10 V. Lower voltages, namely 0 V and 5 V, produced inconsistent or minimal reductions. A one☐way ANOVA confirmed a statistically significant effect of voltage on turbidity change. These findings suggest that 7.2V represents an optimal threshold for effective, low☐maintenance electroflotation that may serve as a chemical☐free method for improving water quality and reducing mosquito larval habitats in stagnant water bodies.

Keywords: Electroflotation, microbubble generation, turbidity reduction, Chlorella vulgaris, stormwater drains, voltage☐dependent performance, low☐voltage operation, mosquito☐control potential, chemical☐free treatment

Deerfield Academy

**Modeling Atmospheric Pollutant Dispersion via Advection–Diffusion PDE and PINN**

Jason Ko

Urban air-quality monitoring networks observe pollutant concentrations at sparse locations, leaving large portions of a city effectively unobserved at high spatial resolution. Physics-informed neural networks (PINNs) offer a mesh-free approach to reconstruct a continuous concentration field by embedding governing partial differential equations (PDEs) into the learning objective, thereby coupling sparse observations with physical
constraints. In practice, however, standard PINN training can converge slowly and exhibit localized PDE-residual hotspots in regions that are weakly constrained by sensors or dominated by sharp gradients. This paper models atmospheric pollutant transport using the advection–diffusion PDE and solves it with a PINN enhanced by predictive uncertainty quantification and an error-estimator-driven adaptive collocation strategy. Uncertainty
is estimated via Monte Carlo dropout and evaluated through empirical coverage and correlation with held-out error, while adaptive collocation concentrates physics constraints where the model is both physically inconsistent and epistemically uncertain. On a controlled synthetic transport benchmark with analytic ground truth, the proposed approach reduces held-out RMSE from 0.0259 to 0.0142 (45.2% improvement) and decreases the
maximum PDE residual from 0.0748 to 0.0130 (82.6% reduction), demonstrating improved accuracy and worst-case physics consistency under sparse observations.

Index Terms—physics-informed neural networks, advection–diffusion equation, air pollution, uncertainty quantification, adaptive collocation, scientific machine learning

Deerfield Academy

**AI-Assisted Discovery of Novel Layered Double Hydroxide Materials for Nitrate Adsorption**

Andrew Li

Excess nitrate contamination in freshwater systems drives hypoxia, ecosystem degradation, and biodiversity loss through eutrophication. Nationwide, 100,000 miles of river and almost 2.5 million acres of water bodies are affected by eutrophication. Existing nitrate remediation strategies, including bioreactors and membrane separation technologies, are often energy intensive, non-selective under competing ion conditions, or logistically complicated. This study develops novel high-performance layered double hydroxide (LDH) adsorbent for selective nitrate removal with the aid of machine learning and AI agents. A structured dataset of LDH nitrate adsorption performance from peer-reviewed literature was constructed with Dify AI workflow, encoding compositional variables, synthesis parameters, structural descriptors, and adsorption conditions. Based on this constructed dataset, multiple machine learning models were trained to predict adsorption capacity and removal efficiency. The best performing model, a particle swarm optimization-tuned histogram gradient boosted regressor (PSO-HGBR), identified unexplored LDH compositions based on Mg, Al, and La. These candidate materials were then synthesized via hydrothermal methods and evaluated using batch adsorption experiments in real contaminated water samples. Experimental results showed that some candidates exhibited improved adsorption capacity of up to 17.8% compared to the control sample of a well studied Mg/Al LDH sample. This work demonstrates an integrated computational-experimental pipeline for accelerated adsorbent discovery, reducing empirical trial-and-error while advancing scalable solutions to nitrate pollution remediation though some inconsistencies persist.

**A Novel, Affordable, Accurate and Easy To Use Multiparameter Water Quality Probe to Monitor the Cape's Watershed**

Ethan Parmentier

Cape Cod has over one hundred watersheds. Not all of these are actively monitor. Many of these watersheds drain into our water supply, and all of them are crucial ecosystems which we must protect. Most agencies that monitor water health on Cape Cod use different, sometimes proprietary commercial probes. To combat the loss in water quality at a large scale, a scalable solution is required. I have built a prototype which works to address this issue. The prototype costs a fraction of the cost of a commercial probe, and is designed to be fully modular and can easily be adapted to accept a wide range of existing sensor equipment. The probes relative accuracy was measured by deploying it next to an industry-standard probe located at the Waquoit Bay Estuary Reserve. We would then take the raw data and convert it into more useful metrics (Converting pressure in millibars to depth with the foffonof equation.) and compare the data to the Reserves to find relative uncertainty to a known "good" probe. The results have shown small discrepancies between my probe's data and the Reserve probes, and they agree within margin of error.

**The Smart Irrigation System**

Vansh Mookim

In a world where natural resources are being consumed faster than they can be replenished, it is vital for humans to find ways to conserve resources and be more efficient. With a rising global population, humans have overused natural resources in order to feed so many people cost effectively. According to the World Bank, global food production will need to increase by roughly 50% in order to match rising population levels. Asking an already strained earth to bear more crop in current conditions is unfeasible. Over-use of freshwater has been a big concern. According to the United Nations Food and Agriculture Organization, agriculture accounts for about 70% of global freshwater withdrawals, making it the largest usage of reserves worldwide. However, according to the EPA, 50% of outdoor water use is lost due to wind, evaporation, and runoff caused by inefficient irrigation systems. If we are to lead a sustainable future we must address this issue. While many innovations have been taking place in the commercial sector, little thought has been given to saving water in the home gardening market. The Smart Irrigation System aims to revolutionize this. Using soil moisture sensors, real-time weather data, and a predictive reasoning model, the irrigation system is able to optimize soil moisture levels for healthy plant growth while conserving water by determining the exact length and frequency of watering, adjusting for atmospheric conditions. Users can monitor and control the system from their personal electronics in order to further tailor the plant-growing experience in an accessible and efficient manner.

North Attleboro High

**MagnaClean: Engineering a Magnetic System to Remove Microplastics from Water**

Tejas Gummadala

North Attleboro High

**Microplastic Contaminant Detection in Flowing Water Through High-Resolution Imaging and AI-Driven Classification**

Ivan Sushanth Sudhir

Microplastic pollution is an increasingly serious global issue that threatens environmental systems, wildlife, and human health. Due to their extremely small size and widespread distribution, microplastics are difficult to detect and monitor using traditional filtration and laboratory-based methods. This project presents the development and testing of a prototype real-time microplastic detection system designed to monitor water flowing through a pipeline using artificial intelligence–based image classification. The prototype uses a gooseneck camera positioned above the pipeline to capture live images of flowing water, which are then analyzed by AI models created using Google Teachable Machine and Google Colab.

The system was tested using both clean and microplastic-contaminated water across multiple trials to evaluate accuracy, efficiency, and reliability. Google Teachable Machine provided rapid, near-instant classification results, making it suitable for situations where immediate water-use decisions are required. In contrast, models trained and executed in Google Colab demonstrated higher overall accuracy due to more advanced model architectures and training capabilities, though they required longer processing times. These results highlight an important trade-off between speed and precision in AI-assisted environmental monitoring.

While the current prototype relies on manual valve control, future versions aim to automate the response system by integrating an AI-controlled ball valve that reacts directly to detection results. Additional future improvements include expanding classification categories to reduce false positives and improve accuracy. Overall, this project demonstrates how accessible AI tools can be applied to real-time water quality monitoring and offers a scalable foundation for preventing the spread of microplastic contamination in water systems.

North Attleboro High

**Predicting Plant Stress Using Electrical Signaling**

Swaroop Srinivasan, Shyam Srinivasan

Early detection of plant stress is important for improving agricultural efficiency and reducing crop loss, especially under environmental conditions such as drought and heat. This project investigated whether electrical signaling in plants could be used to detect stress before visible symptoms appear. A spider plant was used, and electrical potential was measured using a digital multimeter with electrodes placed along the leaf surface. Baseline voltage was recorded under normal conditions, followed by measurements after 48 hours of drought stress at one-minute intervals. The results showed that stressed plants exhibited a gradual increase in electrical potential compared to stable control readings. To strengthen the analysis, open-source plant electrophysiology data were incorporated to provide additional examples of stress responses. A simple neural network model was then developed to classify plant conditions based on voltage patterns and changes over time. The model successfully distinguished between normal and stressed states, demonstrating that plant electrical signals can be used for early stress detection and have potential applications in automated agricultural monitoring systems.

Bishop Feehan High School

**Using a Microbial Fuel Cell to Create Electricity from Waste**

Siddhi Shandilya

With fossil fuel reserves projected to deplete within the next century, Microbial Fuel Cells (MFCs) offer a sustainable solution by generating electricity from microbial metabolism. I hypothesized that if I tested three variables—MFC model, substrate, and electrode—the single-chamber MFC, organic waste, and bamboo charcoal would generate the most electricity.

To build the MFCs, I placed electrodes in air-tight containers with a distilled water solution. In dual-chamber models, I connected the anode and cathode using a potassium chloride salt bridge. I tested steel-mesh and bamboo charcoal electrodes in both MFC types for four weeks, recording the final two weeks for stability. I also compared organic waste to garden soil using the steel-mesh electrode as a control.

The dual-chamber MFC reached a stable peak of 344.8 mV (280.2 mV average) with bamboo charcoal, while the single-chamber reached 255.6 mV (224.4 mV average). With steel mesh, the dual-chamber peaked at 340.7 mV (269.4 mV average) and the single-chamber at 231.6 mV (206.2 mV average). Organic waste reached peaks of 340.7 mV (dual) and 231.6 mV (single), significantly outperforming garden soil, which peaked at 191.7 mV and 172.2 mV.

In conclusion, the dual-chamber MFC and organic substrate performed best. Bamboo charcoal outperformed steel-mesh by a 6% margin. While the hypothesis regarding chamber design was refuted, these results suggest that prioritizing these variables can help scale MFCs into a reliable energy source. By connecting the MFCs in series, I generated a total of 1172.7 mV.

Grafton High School

**AquaIntel**

Ryan Gupta

Microplastic pollution is a major threat to our water, but current testing methods are often too slow, expensive, and rely on dangerous chemicals. Inspired by the need for a safer solution, this project designed AquaIntel to make microplastic detection faster and more accessible. The hypothesis was that a YOLOv12n AI model, trained on specialized microscopic datasets, could identify synthetic fragments and filaments with the same accuracy as expensive lab equipment at a lower cost. The AquaIntel prototype uses an AI-powered computing system connected to a microscopic camera. The methodology involved training the YOLOv12n model using a flash-attention backbone for high-speed processing. A key technical innovation is the system's ability to calculate particle size specifically under 250x magnification by processing bounding box coordinates provided by the AI. This allows the system to accurately distinguish between fragments and filaments, providing significantly more detailed data than standard detection. Results successfully validated this chemical-free method, proving that AI-driven virtual sensors can identify these specific morphologies without using any harmful reagents. The software includes an OpenAI Interaction agent, real-time automated charts, and a research log that captures every detection for detailed analysis. To improve accessibility, it also uses text-to-speech. In conclusion, AquaIntel shows that advanced AI can make water quality monitoring available to everyone, offering a simple and affordable way to study the environment. Future research will focus on expanding the training library to tens of thousands of samples and integrating this technology into autonomous aquatic robots to actively filter microplastics from open waterways.

Shrewsbury Sr High

**Utilizing Combined Darrieus and Savonius Vertical-Axis Wind Turbine (VAWT) Integrated Traffic Barriers to Recover Untapped Wind Energy Generated by Major Roadways to Improve Conventional Renewable Energy Systems**

Arjun Mohandass

Electricity underpins nearly every aspect of modern technology and infrastructure; however, global demand continues to outpace the supply of sustainable energy sources constrained by land use, high costs, and infrastructure limitations. This study investigates the feasibility of recovering untapped wind energy generated by vehicular traffic through the integration of combined Savonius–Darrieus vertical-axis wind turbines (VAWTs) into highway traffic barriers. Vertical-axis turbines were selected due to their omnidirectional wind capture, high land-use efficiency, safety, and suitability for dense urban environments. Three turbine configurations: Savonius, Darrieus, and a combined Savonius–Darrieus design, were designed using CAD software, fabricated via 3D printing, and experimentally evaluated under controlled conditions simulating roadway-induced wind shear at a constant wind speed of 5 m/s. Electrical output was measured over fifteen trials for each configuration and normalized by land area to assess power density. Results demonstrate that the combined Savonius–Darrieus VAWT produced the highest average power output (3.30 W) and power density (~1.6 $W/m^2$), outperforming the individual Savonius and Darrieus designs and exceeding the average land-use efficiency of conventional horizontal-axis wind turbine (HAWT) farms by approximately 50%. Statistical analysis using t-tests confirmed that performance differences between turbine designs were highly significant ($p < 0.0001$). These findings indicate that VAWT-integrated traffic barriers represent a viable, scalable, and cost-effective approach to distributed renewable energy generation, capable of transforming existing roadway infrastructure into passive energy-harvesting systems. This work supports further investigation into real-world deployment and large-scale implementation of roadway-integrated wind energy technologies.

**Designing a Robot to Measure Soil Hydrophobicity and Optimize Tilling for Hydration**

Sanvi Venkayala

Wildfires have become a dominant driver of forest loss, causing almost half of all tree loss per year between 2023 and 2024. This is a sharp increase from 2001-2022, when fires accounted for a quarter of annual tree coverage loss (MacCarthy et al., 2025). Forest recovery is only worsened when some areas of soil become hydrophobic, reducing water infiltration and creating conditions that hinder vegetation regrowth. Interventions to remediate hydrophobic soils are critical for supporting reforestation and accelerating regrowth. Although methods such as the water droplet penetration time (WDPT) test are used to identify hydrophobic soils, conducting these processes is labor-intensive and prone to human error. This project focused on the creation of an automated robot for detecting and selectively treating hydrophobic soil. Water droplet behavior was analyzed through an OpenCV computer vision model, which utilized image preprocessing and frame differencing to estimate WDPT values. To classify final-state soil absorption, two ResNet-18 convolutional neural networks were trained separately on sand and topsoil image datasets, enhancing detection across multiple soil textures. The classification models achieved high performance across both soil types, with accuracy of around 83%, while automated WDPT estimates showed strong alignment with manual measurements ($R^2 = 0.994$, MAE = 2.07 seconds). A robotic system was designed in CAD with a rack-and-pinion tillage mechanism capable of adjusting to various scarification depths to treat hydrophobic soils of different severities. By integrating hydrophobic soil detection with adaptive treatment, this approach addresses limitations of existing methods and holds potential for improving post-wildfire soil restoration while minimizing soil disturbance.

Keywords: soil hydrophobicity, soil scarification, water droplet penetration time, tillage, wildfires, OpenCV, convolutional neural network

**Developing a Mobile Thermal Disposal System for On-Site Construction Wood Waste**

Ryan Prendergast

The construction industry faces a critical environmental and economic crisis, with waste hauling trucks generating over 25 million tons of CO2 annually to transport wood waste from construction sites to landfills. Additionally, wood waste that is transported to landfills takes hundreds of years to decompose completely (Wang et al., 2013), totaling 100 million cubic yards every year. The current disposal method, in which wood waste is transported by trucks, costs companies worldwide roughly 25 billion dollars. Existing industrial incinerators are too large for on-site applications, meaning that there are no current solutions that reduce landfill use, cost, and emissions. This project engineered a mobile thermal disposal system designed to neutralize wood waste through high-temperature pyrolysis at the source. Using Fusion 360 simulations, Steel AISI 1018 118 QT was validated as the most effective material to withstand 5,000 hours of operation at 2000°F. Then, simulations were used to determine that a cylindrical burn chamber would be the best shape based on four simulated characteristics.

The project incorporates a cylindrical burn chamber with a natural draft “chimney effect” and a post-cooling magnetic filtration mechanism, with the option to attach a hose to clean ferrous contaminants and put out fires. Results from actual construction site testing and Finite Element Analysis (FEA) demonstrated that the device maintains safe exterior temperatures while reducing on-site disposal costs by 80%. Furthermore, the system eliminates 60% of transportation-related carbon emissions and completely removes reliance on landfills. These findings suggest that localized thermal disposal is a viable, sustainable alternative for construction firms and homeowners to reduce their environmental footprint and operational expenses.

Keywords: wood waste management, high-temperature pyrolysis, carbon emission reduction, mobile disposal system, heat-resistant alloys, magnetic filtration, finite element analysis

Algonquin Regional High

**Autonomous Fixed-Wing UAV Networks for Early Wildfire Detection: A Cellular Automata Simulation Study**

Ethan Li

Wildfires have become increasingly destructive, with the average annual U.S. forest acreage burned rising tenfold over the past four decades. Suppression costs have escalated by billions of dollars, while wildfire carbon dioxide emissions have grown 60% since 2001. This project aims to analyze the viability of deploying autonomous fixed-wing UAV networks for early wildfire detection.

A terrain-influenced fire spread algorithm based on the Alexandridis Cellular Automata framework was implemented within simulated 50x50 km and 20x20 km environments using 5-meter grid cells. Each map was divided into vertical sectors, with one UAV per sector conducting continuous lawnmower-pattern scans. Network size was varied to assess detection performance.

Detection success was categorized by fire area at time of detection: confident success (<0.5 ha), success (0.5-2 ha), uncertain (2-4 ha), and failure (>4 ha). Across over 15,000 total simulations, it was determined that a density of 1 UAV per 100 square kilometers was required for >95% detection success (4 UAVs on 20x20 - 98.8%, 25 UAVs on 50x50 - 96.6%). For 100% success, 6 UAVs on 20x20 (1 per 66.67 square kilometers) and 40 UAVs for 50x50 (1 per 62.5 kilometers) were required.

Results indicate that detection performance remains approximately constant at fixed UAV densities, though larger environments exhibit lower performance due to increased transit and refueling times. These findings support fixed-wing UAV networks as a scalable and cost-effective early detection strategy especially for high-risk forest environments. Future research should incorporate real-world operational factors, such as weather variability, computer vision for fire detection, and integration with satellites and ground-based monitoring systems.

Keywords:
Early Wildfire Detection, Fixed-Wing UAVs, Autonomous UAV Networks, Cellular Automata, Fire Spread Simulation, Climate Change Mitigation, Environment

Westborough High

**Edge AI based Multimodal Detection of Health-Related Emergencies in a Household Environment**

Mia Zhao

In this project, to detect health-related emergencies in a household environment, I built a prototype system combining the low power consumption feature of IoT (Internet of Things) devices and the great AI power of modern VLM (Vison Language Models) on Edge devices. The system includes three modules:1) a gas leak alarming system based on ESP32 microcontroller and MQ4 natural gas sensor; 2) a VLM driven emergency scene summarization system installed on an Edge device (Jetson Orin Nano); and 3) a BLYNK dashboard/APP aiding the communication of the two modules. Here, the dashboard can display the abnormal readings from the gas leak alarming system and then the homeowners can check module 2 for a summary provided by a locally installed VLM model analyzing the video input from the scene. If there is a health-related emergency occurred, then the VLM model will send out an alarm with the description of the scene. A key component of the system is that all the AI inference work is done locally, without a need to connect to a remote cloud service. I tested the system with a couple of experiments, and the results indicate my system having low inference latency(fast), high reliability (reliable) and privacy (safer). This prototype system has the potential to be used more widely than just in a household environment.

Key words: Edge AI, ESP32, Internet of Things (IoT), , Natural Gas detection, Vision Language Model (VLM)

North Reading High

**Using Computer Vision for Local Waste Detection, Classification, and Mapping: A Novel Approach to Optimizing Model Accuracy with Instance Segmentation**

Naveen Stewart

Rampant litter densities are a global issue as industrialization has increased consumer activity, resulting in urban regions with high volumes of trash, with little being known about the specific distribution of these items. Due to the issues of ecosystem health, microplastic emissions, and water pollution, increasing efforts have been initiated to help track and map litter products within regions with the goals of removing litter products or identifying which regions require the most aid. One solution is crowdmapping, a process where community members mark specific regions corresponding to identifying litter and add such instances to a growing database. Applications of crowdmapping are enhanced through the automation of detection, a practice that this project aims to facilitate by engineering a set of Computer Vision models for identifying a wide range of litter products. This design enables the complete identification and localization of 7 litter object varieties within images, with full inference speed across all models combined under 1 second. The developed softwares also show promising accuracy over existing frameworks: as demonstrated through most model F1 scores in the range 0.8 to 0.9 and mAP50 values from 0.8 to 0.95 across models compared to the current benchmarks of roughly 0.7 F1 scores and 0.65 mAP50 currently used in similar tasks. As a proposed application of this software, the models are being implemented into an autonomous litter crowdmapping software capable of user upload and litter identification based on uploaded images.

Pioneer Charter School of Science II (PCSS-II)

**Design and Testing of a Low-Cost Portable Flood Detector for Outdoor Safety**

Nina Lee

This project focuses on designing and testing a low-cost, portable flood detection device intended for outdoor safety in areas lacking reliable early-warning systems. Using a PVC tube and a leak detector, two prototype iterations were constructed and evaluated against criteria including cost, response time, durability, portability, and power efficiency. Iteration 1 showed delayed activation due to unstable sensor placement and weak support, resulting in inconsistent response times. After redesigning the sensor orientation and replacing the stakes with sturdier ones, Iteration 2 achieved immediate alarm activation across all trials while remaining durable and within the $30-$40 cost limit. The results demonstrate that a simple, inexpensive design can provide rapid flood detection suitable for campgrounds and low-resource environments. Future improvements could include stronger mounting hardware and long-term outdoor testing to further validate real-world reliability.

KIPP Academy Lynn Charter School

**Engineering and Prototyping a Solar-Powered, Engine-Integrated Water Filtration and Electrolysis Module for Hydrogen Fueling in Cars**

Binta Kinteh

This study investigates whether a compact on-board solar-powered electrolyzer with a built-in water filtration and distillation system can safely convert water into hydrogen for real-time use in a vehicle hydrogen-combustion engine. A small-scale electrolysis module was designed, tested, and evaluated for its hydrogen production rate, temperature rise, pressure behavior, and safety of its materials using a computational material science simulation, Fusion360. Using engineering strategies, a 3:1 scale engine attachment is modeled with water filtration, solar-powered distillation and electrodes, reinforced materials, ventilation intended to relieve pressure, and management for internal heat. A final prototype created using engineering software Fusion360 (computer aided design/CAD) represents the proposed design, and experimental data provides insight into the achievability, safety, sustainability and the potential cost of an on-demand hydrogen generator for cars.

Malden Catholic High School

**Making Solar Energy More Affordable**

Jacob Grasso, Nathanael Handy

Solar energy is a renewable energy source that helps transition to clean energy. Electricity generated by solar panels reduces pollution and reliance on fossil fuels. While they do produce clean energy, solar panels aren't always the cheapest and aren't always viewed as worth someone's money. Despite what they are made for, solar panels do not always absorb light efficiently. One potential problem is that solar panels can get very hot when absorbing light, which can reduce their efficiency. Solar panels also achieve maximum efficiency when they can absorb as much light as possible. This project investigated whether cheap household materials could improve solar panel performance. It also tested how the tilt angle affected the power output of the solar panel. Small solar panels were tested at multiple angles with three backing conditions: no backing (control), cardboard, and aluminum foil. Three trials were done for each backing at each angle to test both voltage and current. Voltage and current were measured and used to calculate power output. The aluminum foil backing consistently produced higher power output than the control and cardboard, especially at higher angles. These results show that low-cost items can improve solar efficiency and contribute to making solar energy more affordable. Through discovering ways to improve solar energy, we can get closer to a global transition to clean energy, which can overall lead to a healthier planet.

Keywords:
Solar Energy
Clean Energy
Renewable Energy
Solar Panels
Efficiency
Hot
Affordability
Backing
Electrical Power
Control

**Acoustic On-Demand Fishing Gear Release System**

Vikram Hiranandani

Fishing gear with ropes in the water can trap and injure whales. This project tests a new system that removes those ropes until they are needed. Instead of using a permanent rope, the fishing trap stays underwater and is connected to a buoy that is held down by an electromagnet.

To retrieve the trap, a sound signal is sent through the water. An underwater microphone detects this signal. When the correct sound is recognized, the system releases the buoy, which floats to the surface and allows the trap to be pulled up.

This project tests whether the system can reliably detect the correct signal, avoid false triggers, and work in a waterproof setup. Results show that the system can successfully respond to the correct signal while ignoring background noise.

This approach could reduce whale entanglements while still allowing fishermen to retrieve their gear.

Westford Academy

**Machine-Learning Based Modeling of Chlorophyll-a in Massachusetts Bay**

Sherry Ye

Excess nutrient and pollutant inputs in coastal systems can stimulate phytoplankton growth, leading to oxygen depletion (hypoxia), eutrophication, and ecosystem stress that threatens marine life survival in Massachusetts Bay. This study developed and compared five machine learning models (Random Forest, XGBoost, CatBoost, K-Nearest Neighbor, and an ensemble stack) to predict chlorophyll-a as a proxy for phytoplankton concentrations and to identify key environmental parameters impacting eutrophication risk. Historical MWRA water-quality datasets were preprocessed prior to cross-validated model training and evaluation. The ensemble stack model achieved the highest performance, with a cross-validation RMSE of 1.037 ± 0.061 µg/L and a test RMSE of 0.977 µg/L, demonstrating improved accuracy and stronger handling of extreme values. Feature importance analysis identified transmissivity, temporal variables (month and year), dissolved oxygen, salinity, particulate organic carbon, phaeophytin, temperature, and silicate as important environmental parameters, while expected nutrient variables like nitrogen and phosphorus were less influential to chlorophyll-a prediction accuracy. Sensitivity analysis revealed strong positive correlations (>0.85) between salinity and chlorophyll-a, suggesting that physical processes like stratification may influence bloom development. Notably, predicted chlorophyll-a spatial patterns aligned with effluent discharge locations, indicating strong model accuracy in capturing real-world pollutant distribution. Although chlorophyll-a is an imperfect proxy, and limitations include missing data and lacking physical drivers, this study identifies key environmental parameters driving phytoplankton variability, enabling more targeted monitoring efforts and improving the efficiency of eutrophication risk assessment under ongoing environmental change.

**Articulated Arm with Integrated Power**

Neel Thakar

Today electric cars are weak compared to gas cars because of low mileage compared to them- they go half as far as gas cars. For this, scientists made structural batteries but current batteries can't handle the ambient temperatures so the voltage drastically becomes low. Because of this I am testing whether liquid cooling/insulating system for engines can also work for batteries as both have different requirements and conditions. Research question: which liquid - 5% citric acid, vinegar, water - will be effective in stabilizing temp of battery? My hypothesis: If a lithium battery is surrounded by these 3 liquids and put in cold and hot water at 5C and 55C then one with water will have highest average voltage because water has highest specific heat. I put the lithium batteries in those three cases holding the three liquids and then put that in water at these temps for two hours, and then kept out for another two hours. Took the voltage of the batteries after taking them out and leaving them out for two hours. Took the average of the voltage data for battery in each liquid and found hypothesis was wrong. Battery with vinegar had 1.804 voltage compared to 1.801 voltage with water due to unequal amount of liquid or acidity but overall vinegar was best at regulating temp. In future this experiment will be done with just vinegar and other properties as independent variables.

**Molecular Dynamics Studies of Underwater Adhesion Using Bio-Inspired Peptides**

JinXuan Qi

**Protein Conformational Transitions: Pathway Modeling Using Nudged Elastic Band and Linear Interpolation and Its Application to Methane Mitigation**

Jessica Wu

Proteins frequently undergo conformational changes to achieve optimal protein and ligand binding, yet experimental techniques often capture only static, unbound and bound endpoints. Mapping the continuous, low-energy transition pathways between these states is critical for designing specific drugs, especially for challenging allosteric targets. In this study, we applied an optimized Nudged Elastic Band (NEB) protocol using AmberTools 2023 (AMBER99SB-ILDN force field, implicit solvent) to map the transition pathways of two Benchmark 5.5 Dataset proteins: 1J57 (NuiA nuclease A inhibitor) and 1CKV-A(9) (regulatory protein B). Our modified NEB protocol reduced computational time and prevented protein unfolding and denaturation, identified intermediate conformational changes, and found converging global minimum energy paths (MEP). The MEPs revealed distinct conformational mechanisms due to different types of motion (loop vs. hinge): even at high potential energy, 1J57 exhibited structural rearrangement along the while 1CKV-A(9) remained relatively static. Docking ~4000 ZINC small molecules to the transition state (TS) identified candidates that reduced potential energy (up to 2.2% in 1J57), suggesting faster, more efficient binding. These results show that targeting intermediate, high-energy transition states, rather than only the final bound structure, can lead to more efficient, faster-binding drug candidates. This work supports the strategy of transition-state stabilization to improve hit identification and identify allosteric modulators in structure-based drug design, particularly in developing therapeutics for cancer and neurodegenerative diseases such as Alzheimer’s. Future studies will investigate diverse conformational motions (i.e., loop, hinge, lock and key) and the effects of mutation on larger, disease-relevant proteins, including G-Protein Coupled Receptors (GPCRs).

**Investigating Pluvial Flooding in Brockton Using AI and a Physical Rainfall Model**

Nathanael Pierre

Urban pluvial flooding is becoming an increasing risk in cities due to climate change, aging infrastructure, and large impervious surfaces such as parking lots and roads. This research investigates whether artificial intelligence (AI) can improve flood prediction in Brockton, Massachusetts. The study combines a physical rainfall experiment with a machine learning model trained on environmental datasets. Results from the physical experiment showed that smaller drainage diameters significantly increased the time water remained on the surface, leading to flooding conditions. The machine learning model analyzed 4,558 records containing 48 environmental variables including rainfall intensity, land cover, slope, and drainage capacity. The AI model achieved a receiver operating characteristic area-under-curve (ROC AUC) score of approximately 0.846. The model also correctly identified the Westgate Mall area as a severe flood-risk location consistent with documented flooding events. These results suggest that AI-driven flood forecasting could provide earlier warning times and help cities better prepare for rainfall-driven flooding.

**Best Sound Insulators**

Camden Gareau

I decided to do my science fair project on Sound Insulation because I thought it's interesting how you do not hear people from other rooms in school and at your home. This made me wonder what is the best material for insulation for sound. The purpose for this experiment is to find out what is the best insulation that you can get while also staying relatively cheap. My hypothesis was that if a type of sound insulation will be better than the rest, then it will be wedge insulation because of its triangular shape and foam making it able to absorb the sound that is played. The expected outcome I thought would be from best to worst wedge insulation, Eggcrate Insulation, Sound Deadening Mat, Spray-In-Insulation and Control. In my experiment I surrounded a speaker with a type of insulation and a cardboard box. Then I would play white noise at 50% volume. Next I would hold my phone with a decibel reader 1.5 feet away and see how many decibels were permitted. When I tested with control my phone measured 66 decibels. For Spray-In-Insulation it permitted 65 decibels. Eggcrate Insulation did the best permitting only 60 decibels. When it was Wedge Insulation there were 61 decibels permitted. Lastly the Sound Deadening Mat allowed on 63 decibels to pass.

**Optmizing Collector Electrode Geometry for Electrohydrodynamic Propulsion Systems**

Tanay Apte, Mihir Jain, Varvara Karenski

This project investigates the effect of collector electrode geometry on the thrust of single-stage electrohydrodynamic (EHD) thrusters. EHD thrusters are silent and feature no moving parts, which makes them promising alternatives to small-scale drone propellers. However, their low thrust density remains a major hurdle. A significant contributor to this inefficiency is the aerodynamic drag generated by the collector electrode, which acts against the generated thrust. Using a customized low-friction force measurement setup, our team deduced how different geometries of collector electrodes change the net thrust, with a focus on the annular airfoil shape. The thruster was tested with a constant voltage of 8 kV, at a constant electrode gap of 1 inch. A negative correlation was observed between thrust and thickness, camber and convergence angle of the annular airfoil. These findings suggest that while a slimmer airfoil shape improves aerodynamics, minimizing the collector's frontal area remains critical for maximizing EHD propulsion efficiency.

**Turning The Tide**

Kaya Doucette

Hydropower has been long long before modern uses of electricity, but is it as efficient as it could be? What blade shape would generate the most voltage in a water turbine,  that is the question this project is set to answer. Theoretically a curved blade would produce the most voltage and have the highest efficiency.  4 different blade shapes were desgined and 3D printed, a curved, beveled, cross beveled, and the control, a flat blade. Water was pumped through a dam head at a flow rate of 106.25 ml/s. Each blade was tested for ten seconds ten times. The best peforming blade was the curved with an average of 1 voltage per second reaching peaks of 1.03 V. The worst peforming blade was the flat, having an average of only .76 V per second. The hypothesesis was proven correct. This can applied to larger turbines so that green energy can be even more effiecnet.

**The Effect of Beadwork Thread Material on Thread Strength**
AJ Trowbridge

The purpose of this experiment was to determine which material of beadwork thread – rayon, cotton, nylon, or polyethylene – could withstand the most force before breaking. By determining this, beadworker artists can improve the tensile strength of their pieces. It was hypothesized that polyethylene thread would be able to withstand the most force, because of its continuous filament structure and "super drawn" macromolecules. To test the hypothesis, ten trials of each material of thread were tested, with each trial being 12" and with a knot tied at each end using 2" of thread. The apparatus was a pulley system, with weight at one end and a clip at the other. The thread was attached to the clip and force probe, which recorded the amount of force, so that when the weight was dropped from table height, it pulled on the thread, which in turn pulled on the force probe. When the thread broke the force rapidly decreased, and the peak on the resulting graph was each trial's maximum force. The data was analyzed by taking the average of the maximum forces, as well as by using a t-test. It was determined that polyethylene beadwork thread had the highest average maximum force, followed by nylon, cotton, and rayon. All materials also exhibited statistically significant differences from one another. The reason this occurred was likely due to the differing constructions of the threads, both on a fibrous and molecular level.

**Is Synchronization Fundamental? How Mechanical Systems and Harmonic Forces Mutually Shape Each Other**

Esmael Peavey

Previous theoretical work suggests synchronization effects drive precession in binary star systems. However, whether this reflects a deeper universal principle remains an open question. This project investigates synchronization as a fundamental process through both physical experimentation and theoretical analysis.

A physical experiment using mechanical metronomes demonstrated that coupled oscillators on a freely moving platform synchronize, while a fixed platform prevents synchronization.

Mechanical metronomes on a freely moving platform synchronize by transmitting angular momentum through the platform. Fixed platforms prevent this transmission, blocking synchronization. This mirrors Einstein's insight that spacetime tells mass how to move and mass tells spacetime how to curve. Analogously, harmonic forces such as gravity and electromagnetism interact mutually with binary star mechanics, producing orbital shifts or precession. Synchronization will not occur when mechanics or harmonics are restrained. Binary stars are used to test the fundamental nature of this coupling. Systems evolving freely tend toward synchronization, representing a lower energy state.

Binary stars test this coupling. This study examines a field-coupling model applied to ten benchmark systems including DI Herculis, V541 Cygni, AS Camelopardalis, and seven double neutron star binaries. Results show the model aligns with observations across all systems, with varying precession rates. Binary stars represent different coupling regimes of the same harmonic-mechanical interface, supporting synchronization as a fundamental process woven into physical law.

Keywords: synchronization, binary stars, precession, field coupling, equilibrium, harmonic and mechanical forces, apsidal motion

**A Recipe for Success: The Effect of Variation in Bioplastics Recipes on the Tensile Strength of the Bioplastics**
Anna Mahoney

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Plastic pollution is one of the leading issues in our world today and modern day bioplastics are not as widely used due to their inferiority in properties compared to conventional plastics. This project aimed to develop all natural bioplastics that were strong enough to be applied to real-world situations. Eight different kinds of bioplastic were made and their tensile strength (along with stretch length) was put to the test. The two bases used were tapioca starch (four groups) and gelatin (four groups). Three additives to increase tensile strength were gauze, eggshell powder, and citric acid. It was hypothesized that the starch-based bioplastic with the gauze additive would have the greatest tensile strength followed by the gelatin-based with the gauze additive, the starch-based with the citric acid additive, the starch-based with the eggshell additive, the gelatin-based with the citric acid additive, and finally the gelatin-based with the eggshell additive with the lowest tensile strength (the control groups for each base would be weakest). To conduct the experiment, the groups were all made using the appropriate recipes and processes and strings were glued to either end of each strip. They were tested using a hanging force probe that revealed the maximum amount of force exerted on each individual before it broke when pulling down on it. The stretch length was measured with a ruler and by videoing the testing. In the end, the gelatin-based group with the gauze additive actually had the highest tensile strength followed by the gelatin control group, the starch-based gauze group, the gelatin-based eggshell group, the gelatin-based citric acid group, the starch control group, the starch-based eggshell group, and finally the starch-based citric acid group. The gauze additive was strongest as predicted. The eggshell additive and citric acid additives weakened the bioplastic tensile strength likely because the eggshells resulted in a more brittle bioplastic while the citric acid resulted in a stretchier and flimsier bioplastic. The gelatin-based bioplastics actually turned out to be stronger and firmer than the starch-based ones, contradicting the hypothesis. In stretch length, the citric-acid groups were the stretchiest, suggesting an inverse relationship between stretch length and tensile strength. Ultimately, the gelatin-based gauze group would likely be most applicable to real-world situations and for further research other properties of this plastic would be studied and improved on such as its biodegradability, its heat resistance, and its water resistance.

**The Strength of Softness - Redesigning The Whipple Shield**

Zachary Chiu

Spacecraft operating in Earth’s orbit are constantly exposed to micrometeoroids and orbital debris (MMOD), which pose a serious risk despite their extremely small size. Many MMOD particles are less than 1 millimeter in diameter, yet they travel at extremely high velocities, between 7 to over 15 kilometers per second in low Earth orbit. At these speeds, even the tiniest particles can easily puncture spacecraft surfaces or damage critical systems.

As of recent estimates, there are over 128 million pieces of MMOD larger than 1 millimeter in Earth’s orbit, meaning that spacecraft face a high impact risk when launching into space. To reduce this risk, spacecraft use Whipple shields, which fragment incoming particles and disperse their energy before it reaches the main spacecraft.

This project investigates how different internal geometries in 3D-printed Whipple shield models affect impact resistance. Four shield designs, Warren truss, thin layer, octagon, and thick layer, were 3D printed with equal overall thickness and tested using a vacuum-powered cannon inside a sealed acrylic enclosure. Each design was subjected to both single-impact and repeated-impact tests under identical vacuum conditions. Penetration depth and weakened area were measured and compared across designs. The results show that internal geometry significantly influences how impact energy is absorbed and distributed, especially in the thin layer shield. Certain designs reduced penetration by spreading damage across a wider area, while others performed better because of their flexibility. These findings demonstrate the importance of internal structure in Whipple shield design to improve spacecraft protection against MMOD impacts.

**Using the Magnus and Seam Shifted Wake Effects to Find the Perfect Pitch in Baseball**

Kevin Azizi, Khang Nguyen, Travers Moodie

In baseball, pitchers have to control speed, spin, grip, and aim whilst competing against hitters who can react with split-second actions. Small physical differences can change whether a pitch is successful or gets hit back. Our project will explore how physics and the Magnus Effect can get the perfect pitch in baseball. The Magnus Effect is the idea that a ball hit in an area of pressure from air or water will curve. In Baseball, this is especially prominent and involves a lot of fluid dynamics whenever a batter hits the ball or a pitcher throws it. For our project, we plan to use publicly available data from select Major League Baseball pitches found in Statcast and dictate how well they obey the Magnus effect, and potentially use them to observe the limits of how much a pitch can curve and how it could be utilized in a real match. The main question we'd like to find out is, "What velocity is the perfect curved pitch in baseball that is humanly possible, and under what conditions does the Magnus effect break down?" To find this, we will need to get calculations on the resistance to pressure to characterize the flow type (laminar vs turbulent), and the lift coefficient, which will be the primary metric for determining aerodynamic efficiency. With efficiency, we can determine what the best pitch type is and at what spin and velocity. Our project could potentially create a competitive advantage for players and grow the sport's popularity.

Keywords: Magnus Effect, Pressure, Density, Flow Velocity, Boundary layer, Flow Separation, Lift Force, Seams, Bernoulli’s Principle, Seam-Shifted Wake Effect, Turbulent Flow, Laminar Flow, Spin axis, Spin axis deviation

**Unraveling J/ψ Production Mechanism: Extraction of J/ψ NRQCD Long Distance Matrix Elements through Bayesian inference**

Yubo Liu

The production mechanism of the J/ψ meson in hadron collisions has long been an unresolved problem in quantum chromodynamics. In the non-relativistic quantum chromodynamics (NRQCD) framework, production is governed by long-distance matrix elements (LDMEs), which encode non-perturbative effects and must be determined from experimental data. Although there are multiple attempts to extract the LDME of J/ψ, the results vary due to their different kinetic and energy ranges. In this work, we developed a multi-dataset Bayesian inference framework to extract an effective, globally consistent set of J/ψ LDMEs across proton–proton collision data spanning multiple energies and rapidity regions in different institutes across 15 years. For each published dataset, we reproduced the results using the Monte Carlo event generator PYTHIA 8.3.15. We then utilized the event records to produce the specific differential prompt cross-section for each channel and production process. We then performed a hierarchical Bayesian fit in PyMC to extract the global LDME parameter across the different datasets and conditions. The resulting posterior distributions exhibit strong convergence diagnostics ($\hat{R} \approx 1$ with high effective sample sizes) and significantly improved agreement between simulation and experimental measurements. Notably, the refined model achieves 86% coverage of experimental data points within its posterior predictive uncertainty bands. This represents an improvement of approximately 40 percentage points compared to typical coverage levels in previous LDME studies, corresponding to substantially stronger predictive performance on unseen data. In addition, the long-standing degeneracy between the □O(1S□[8])□ and □O(3P□[8])□ channels, which has been a persistent problem in LDME extractions across the field, is significantly suppressed by the inclusion of physically informed priors: the Spearman correlation is reduced from −0.47 in the baseline model to −0.20, corresponding to an approximately 57% decrease in correlation magnitude and indicating substantially improved parameter identifiability. These results demonstrate that the Bayesian inference framework provides a coherent and scalable approach towards combining heterogeneous measurements and extracting universal LDME parameters. Furthermore, the model's predictive ability demonstrates the generality of LDME, thereby justifying the universal assumption of the NRQCD framework.

**Bridging Sleep Instability and Brain Criticality Using the Ising Model**

Mira Xu

The critical brain hypothesis frames the brain as operating at a near-critical point that can optimize information transfer and response to stimuli. However, the body also needs to maintain certain homeostatic processes such as sleep to keep the brain at a quasi-critical state. One particular perspective involves the role of cyclic alternating patterns (CAP) in non-REM sleep to fine-tune the brain to criticality. To investigate this idea, this paper compares CAP A1 phase correlation with neuronal avalanches and long range temporal correlations (LRTCs) of 15 individuals with no sleep pathologies from CAP Sleep Database to other phases of CAP and sleep. We found that the brain exhibits neuronal avalanches during sleep with an avalanche size critical exponent of $1.506 \pm 0.049$ and avalanche duration critical exponent of $2.076 \pm 0.226$. Among all phases of sleep, CAP had a statistically significant increase in neuronal avalanche correlation and LRTCs. Among different CAP A phases, A1 had a statistically significant increase in neuronal avalanche correlation and LRTCs. Most importantly, we propose a simple modified mean-field Ising model to investigate criticality in the brain during sleep. The model provides insight into the physical mechanisms underpinning CAP A1's role in fine-tuning the brain to criticality.

**How Does Changing the PWM Duty Cycle Affect the Magnetic Field Strength and Core Saturation Behavior of an Electromagnet with and without a Soft Iron Core?**

ZiHua Mai

This study investigated the effect of pulse width modulation (PWM) duty cycle on the magnetic field strength and saturation point of the electromagnets to analyze the non-linear relationship between current and magnetic flux density (B), identify the core's saturation point, and calculate the core's magnetic permeability. Electromagnets rely on ferromagnetic cores like soft iron cores to amplify their magnetic field. However, these cores have a physical limit or magnetic saturation. When the current increases beyond saturation, it yields minimal extra field strength while significantly increasing resistive heating.
We used an embedded system to generate PWM signals to regulate the current on the electromagnet via a MOSFET system across duty cycles from 0% to 100%. Trials compared the magnetic flux density with a soft iron core inserted in the wound coil and the air core configuration. A Hall sensor was used to measure the axial magnetic flux density at the pole, while a current sensor recorded the input current across duty cycles. The data was used to plot the B-I graph for both cases and estimate how magnetic permeability (mu) changes with current. When the PWM duty cycle was increased, the current increased at an increasing rate while the magnetic flux density increased linearly before plateauing, and the air core B increased proportionally to the current. Therefore, applying a precise current cap to electromagnet coils prevents unnecessary energy waste and mitigates material degradation.