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Chemical Engnineering

Understanding a Natural Pollution Control Performed by Bacteria

Specific bacteria found in rice fields are responsible for controlling the level of methane (natural gas), a dangerous pollutant in the atmosphere. Large molecules, known as enzymes, inside these bacteria are responsible for chemical reactions that convert methane and oxygen from the air into other substances. My research work focuses on the understanding of how these enzymes work cooperatively in nature using computer simulations. Particulate methane mono-oxygenase(pMMO) is one enzyme that has the ability to convert methane to methanol. The interaction between atoms in this enzyme can be studied through the use of molecular modeling. Through the use of software, an oxidation mechanism is evaluated to determine how the enzyme is able to convert methane to methanol. In this research, the enzyme acts as a catalyst, allowing for the reaction to occur. The practical application of this research is that results obtained from these studies can be used to provide information about catalysts to more efficiently create biofuels.

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Particle Physics

K-12 Students and Teachers and the Large Hadron Collider at CERN in Geneva, Switzerland

About eight years ago the Compact Muon Solenoid (CMS) experiment dedicated a data stream to NSF's QuarkNet Project, a national K-12 outreach in particle physics. The CMS experiment is located on the 17-mile Large Hadron Collider ring, the highest energy accelerator in the world, at CERN in Geneva, Switzerland. This data stream will be the only publicly available data distributed by CMS. The data which appears on any particular data stream are selected from the vast quantities of data collected every second by the CMS data acquisition system. These selections are based on selection criteria particular to each data stream. The selection criteria are in-turn based on the topography of the event: the number of electrons, the number of muons, the number of hadronic jets, the presence of neutrinos and the transverse momenta of these detected objects. We decided that the first publicly available data from the CMS experiment should be among the most straight-forward data to analyze. For this reason, we decided to select events that were likely to contain Z bosons, the electro-weak force carrier that is about 100 times more massive than the proton. The large mass and unique decay modes of the Z boson facilitates its reconstruction and identification immensely.
We will present event selection criteria studies of CMS simulated data. The analysis of this data has allowed us to recommend to the CMS collaboration selection criteria for Z bosons decaying into two oppositely charged electrons or muons.

We hope that the data selected based on our studies will soon be analyzed by K-12 students and teachers world-wide. This work was a collaborative effort of a 12th grade student and myself.

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Chemical Engineering

Optimized Two-Phase Heat and Mass Transfer through Enhanced Liquid/Vapor/Surface Interactions Involving Micro Pin-Fins and Self-Assembled Monolayers

The continued world energy crisis and rise in electronic component power dissipation with heat fluxes approaching 1kW/cm2 has turned renewed attention to novel thermal management systems. The thermal performance of these systems depends on optimizing the liquid/vapor, liquid/substrate, and vapor/substrate interactions. My research proposes to use molecular engineering approaches to modify a copper substrate. By first uniformly machining a copper surface with micro-pin-fin features, then selectively sputtering a thin gold layer on only the top of those features, and finally using a weak chemical reaction to make self assembled monolayers (SAMs) from bonding hydrophilic and hydrophobic thiol groups to only the gold layer. This will create a hybrid enhanced surface that will combine the benefit of increased area for heat transfer through the micro-features, with the enhanced interfacial properties and structure of an ultra-hydrophilic/ultra-hydrophobic surface for improved mass transfer. This will extend the understanding of heat removal as it applies to the electronics, aviation, and national security/military industries. To the consumer this will result in smaller, cheaper, more reliable, and faster personal electronics.

I am currently integrating my research into the K-12 classroom through activities that investigate fluid properties, hydrophilic/hydrophobic behavior, heat transfer, and principles of energy conservation and alternative energy sources. These classroom activities demonstrate how aspects of my research are related to students' own experiences of how things work and behave. The activities present students with the perspective of an engineering design need and they proceed to explore viable solutions that are grounded within engineering principles.

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Heat Transfer - Mechanical Engineering

Multiscale simulation of heat transport in microelectronics

Nanotechnology research has exploded within the last 50 years due to advancements in microscopy and material fabrication techniques. Currently, it is possible to fabricate electronic devices with dimensions on the order of tens of nanometers. Commercially available products, such as Intel's Core 2 processors, are based on transistors that have a length scale of only 45nm; approximately 2000 times smaller than a human hair. As new device technologies leave the physics research lab and migrate toward commercialization, there is a need for engineers to become intimately involved in the final design. As part of this design process it is helpful to have some predictive tools to help guide the process. Tools such as CAD programs and finite element packages have been the workhorses in many engineering departments and are considered indispensible. While these packages serve many of the needs for traditional (i.e. large) engineering applications, there are gaps that must be filled if these tools are to be applied to the field of nanotechnology. At the opposite end of the size spectrum, there are specialized tools that are designed to simulate individual atoms; however, the computational burden of applying these tools to engineering applications is prohibitive. Ideally, a simulation tool that can span the range from the "very small" to the "not too large" should be developed. Developing these so-called "multiscale" simulation tools is where I found my current research topic. I am currently focused on developing multiscale simulations of how heat is generated and transported in high power electronics. With input from these predicative tools it is the hope that next generation devices will benefit from wider application and higher device reliability.

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Ecology

The impact of biological invasions on river otters and aquatic-terrestrial linkages in Yellowstone Lake

Two nonnative stressors, lake trout and whirling disease (caused by Myxobolus cerebralis), have contributed to a severe decline in the native cutthroat trout population of Yellowstone Lake, in Yellowstone National Park. North American river otters (Lontra canadensis) are one of several Yellowstone Lake predators that depend on cutthroat trout as prey, especially during summer when the fish make spawning migrations from the lake into tributary streams. As part of their social behavior, otters deposit excreta at latrine (scent-marking) sites along these spawning streams and fertilize streamside plants with aquatically-derived nutrients such as nitrogen and phosphorus. However, since the introduction of lake trout, numbers of spawning cutthroat trout have declined by more than 90% in some tributaries of Yellowstone Lake. Continued declines in the availability of cutthroat trout may reduce the abundance and distribution of otters and effectively sever the nutrient link between water and land. Presently, a lack of abundance data for otters limits the ability to evaluate whether exotic introductions in Yellowstone Lake have indeed disrupted these nutrient linkages. In this project, I am using DNA analyses to estimate the number of river otters in Yellowstone Lake, reconstructing the otter population with bioenergetics carrying capacity models, and evaluating historical declines in river otter abundance and nutrient transfer through analyses of stable isotope ratios of nitrogen in tree rings from trees growing on otter latrine sites.

I use information from this project in the K-12 classroom to teach ecological concepts and scientific methodology. In addition, my research illustrates to students that humans can have far reaching, long-term effects on the environment.

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Geoscience

Geochemical and lithologic signatures from Marie Byrd Land and Larsen-B Ice Shelf sediments: Implications for Antarctic provenance tracing

The implications for global sea level rise rely on the stability of polar ice sheets, as they remain the world's largest freshwater reservoir. We have focused on two regions of Antarctica, Marie Byrd Land (MBL), and the Larsen-B (LIS-B) embayment on the northeast Antarctic Peninsula, which have undergone recent ice shelf retreat and possibly past episodes of ice sheet collapse, respectively, and pose the potential threat for sea level rise. The bedrock in these areas has characteristic lithologic and geochemical signatures that are preserved in glacially transported and deposited sediment and may allow us to identify ice rafted debris and fine-grained sediment that originate from these two areas. This study involves the determination of characteristic features of near-shore glacial-marine sediment from each source area that are representative of the sub-ice bedrock, which is largely inaccessible. Bulk sediment elemental abundances were measured from <63μm sediments. Geochemical data from MBL yields Al/Ti values of 15-21 suggesting a continental crust source or possibly a mixture of upper continental crust and mafic intrusions. εNd values from samples within MBL range from -2.3 to -8.3. Samples from LIS-B yield Al/Ti values of 21-30, suggesting an upper continental crust source. εNd values range from -1.9 to -4.9, and are distinctly different from values observed in the central Weddell Sea to the east, and in the northwestern Antarctic Peninsula. Thin section grain mounts of the coarse sediments used for lithology identification in conjunction with geochemical results allow us to assign source area fingerprints for both MBL and LIS-B. Classroom connections include seafloor mapping, radiometric dating, paleoclimate reconstruction, and handling Antarctic marine sediments.

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Biological Sciences

Organization and bacterial assemblages of the glandular papillae of the comb jelly Mnemiopsis leidyi

Mnemiopsis leidyi Phylum Ctenophora: Class Lobata is a marine, gelatinous metazoan predator common to coastal Gulf of Mexico and the Eastern United States. It is a notoriously invasive animal commonly undergoing transatlantic transport via ship ballast water. M. leidyi is exceptionally thermo- and euryhaline, allowing it to become established in virtually any coastal and near-coastal marine habitat. An intriguing feature of its anatomy is a collection of wart like glandular papillae, found in and just below the epithelium. Papillae are much more common on large, presumably older individuals, which may have hundreds of papillae. Papillae tend to be concentrated on the aboral epithelium, and on the outermost surface of the proximal-lateral aspects of the lobes, although in very large individuals they may be present on the entire outer surface epithelium. Virtually nothing is known about the papillae, although it is thought that they secrete mucus. We show here that papillae are a distinct organ system, being consistently composed of several discrete components, which have distinct functions. Papillae are supported by a basketlike arrangement of smooth muscle fibers, which underlie 1 to 12 large central gland cells, each of which bears a colored oil droplet. Hoechst staining and fluorescence imaging reveal the basal location of the gland cell nuclei, and the presence of numerous bacteria. Noxious stimulation of papillae results in the contraction of the muscular basket, eversion of the gland cells, and release of mucus. A 16S rDNA analysis of papillar bacterial assemblages indicates a wide diversity of bacterial taxa relative to the bacterial diversity of surrounding water or the gut. Ongoing analyses seek to determine the structure/function relationships between M. leidyi and its bacterial assemblages.

At the beginning of the year I introduce my research project to my students through a brief presentation and a hands-on activity. This gives the students a first hand look at Mnemiopsis leidyi, the organism used in my research, allowing them to see and touch an animal they don't see on a day to day basis. I can then integrate my research into lesson plans throughout the school year to reinforce concepts that the students are learning. This demonstrates a connection between the fundamental scientific concepts learned in class and science performed in research environments worldwide. The in class activities also generate an interest in the multiple career avenues available in science and show students how science can be seen and applied in everyday life.

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Evolutionary Biology

A study of variation between populations of a native Hawaiian Picture-winged Drosophila on the Big Island of Hawaii

The Big Island of Hawaii, a conglomeration of five volcanoes that range from active to 700,000 years dormant and reach up to nearly 14000' above sea level, contains nearly all of the world's major ecotypes. Within this relatively small land area there are arid deserts and thick rainforests, barren lava flows and deep fertile soil, continuous tracts of forest and naturally fragmented islands of habitat. In many cases these disparate environments are found within a few miles or even a few feet of each other, though both between and within them there are clear and often continuous gradients of temperature, humidity, soil quality, and even biomass. These conditions make the Big Island an ideal location to study the mechanisms that drive the differentiation of populations, a precursor for speciation and a fundamental part of our understanding of the generation and maintenance of biodiversity. The Hawaiian Drosophila flies are an ideal group of species to study local adaptation, population genetics, and speciation. Thought to have derived from a single wind-blown founder over 10 million years ago, these flies have radiated tremendously and there are estimated to now be at least 700 endemic species. Using the natural laboratory of the Big Island, I am investigating the role of distance, fragmentation, and environmental gradients in producing population differentiation within a nearly unknown species, D. sproati. Now the most common and widespread species among the well studied "picture-wing" group on the island, D. sproati is found on all 5 volcanoes and within a 2000' range. I am currently assessing variation between D. sproati populations using mitochondrial and nuclear neutral genetic markers and through multiple temperature-tolerance measures of local adaptation.

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Mechanical Engineering

Heat Pipe/Micro channel Heat Exchanger: A Thermal Performance Comparison

The main aim of this research is to design, model and test a heat pipe heat exchanger (HPHE). Heat exchanger is a thermal device which is used to transport heat between moving fluids at different temperatures. Heat exchangers are widely used in many different applications and industries worldwide, varying from space, energy, transportation, heating and air conditioning, etc. Heat pipe is a thermal device which usually consists in a sealed cylinder with a fluid inside to transfer the heat from the evaporation side to the condensation side. Heat pipes are known for being one of the most efficient heat transfer devices in actual times. Early heat pipe designs and research were mostly focused in aero spatial applications due to its ability of moving the fluid with no external pump of force. Although the idea of utilizing a wick structure to provide the capillary pumping in the heat pipe application goes back to the 1940's, it was not until 1984 that the combination of micro scale fabrication and two-phase heat transport was proposed. After the proposal for this type of heat pipe, a variety of designs and applications can be found such as: heat removal from laser diodes, thermal control in photo voltaic cells, refrigeration cycles, space applications and nonsurgical treatment of cancerous tissue. Due to their design, micro-channels tubes are devices with a high surface area over volume ratio allowing designers to use less working fluid and obtain similar or better heat transfer rates.

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Geography

The Historic Dendroarchaeology of the Ximenez-Fatio House, St. Augustine, St. Johns County, Florida

Over recent decades, agencies charged with managing historic structures have found dendroarchaeological studies increasingly valuable, given the ability of such studies to verify construction dates. The Ximénez-Fatio House has historical and cultural significance for the state of Florida, as it is one of St. Augustine's most authentic historic properties. St. Augustine is the oldest continuously occupied European-established city in the continental United States, and the Ximénez-Fatio House is located in the center of the city's oldest community. The original housing structure was reportedly built ca. 1797. The only major structural renovation to the house was the addition of a 2nd story wing sometime during 1830—1842. However, certain historic architects believe the entire wing of the house was constructed in the 1850s. Through the use of tree-ring dating, our goals were to (1) determine the probable construction year for the original structure, and (2) verify the probable construction year for the renovation that occurred in the wing section of the house. A total of 74 core samples were extracted from longleaf pine (pinus palustris Mill.) timbers used to construct the house, twenty-two of which were used to build a floating tree-ring chronology 177 years in length from series that were confidently crossdated both visually and statistically via COFECHA. We then statistically evaluated the probable temporal placement of this chronology using a nearby reference chronology. A statistically significant ($p < 0.0001$) correlation between our chronology and a longleaf pine chronology from Lake Louise, Georgia anchors our chronology between 1680—1857. Cutting dates obtained from timbers revealed that the entire wing of the structure was built ca. 1858.

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Physical chemistry

Efficiency and photocurrent response studies of photoelectrochemical cells

Development of high efficiency solar cells is a critical direction in the pursuit of renewable energy. One of the most promising designs for converting solar energy into electricity is the photoelectrochemical (PEC) cell. In PEC cells, an absorbing sensitizer harvests light and injects an electron into the conduction band of a semiconductor, which transports the electron to the electrode. The circuit is completed as the sensitizer is recovered by means of an electrolyte pair. Optimization of the cell efficiency is contingent upon quantum efficiency of light absorption, injection rate, and electron transport among other processes. In this study, PEC solar cells have been constructed using several combinations of absorbers and nanostructured wide band-gap semiconductors. Among the materials used as sensitizers are the low band-gap semiconductor, gallium arsenide (GaAs), and a ruthenium dye (N719, black dye), while the semiconductor materials include GaAs (direct absorption), titania (TiO_2) and tin oxide (SnO_2). The kinetics of electron transport in these cells have been examined through photocurrent decay measurements initiated by a pulsed laser. The global power conversion efficiencies have also been determined.

This research is pertinent to the concept of energy transfer and provides a real world example of energy conversion. These are both concepts that are generally a part of the GK-12 curriculum. The topic of solar cells can also be integrated into the classroom through a discussion of renewable and nonrenewable energy sources.

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Solar Physics

Ulysses observations of periodic structures in the solar wind velocity

Knowledge of the presence and evolution of periods in the solar wind at out-of-ecliptic latitudes can give information about the latitudinal structure of the solar wind and help distinguish between theories that predict the global characteristics of the solar wind and heliosheet. We have computed the spectrogram of the plasma velocity measured by the Ulysses spacecraft in the interval of 1991--2008 in the range of 5-- to 40--days and confirmed periodicities observed in previous limited-time-interval studies. The most prevalent period in the spectrogram is the solar equatorial rotation period observed at most Ulysses radial distances. Periods around ~13.5--days also occur with strong amplitude; many of those are not harmonics of the 26--day period. An example occurs in 2002 when Ulysses was at high-latitudes when a clear 13.5--day period is present without an accompanying 27--day period. The spectrogram also reveals 14--, 23--, and 30--35--day periods while Ulysses was at high southern latitudes in 1994 and 2007 which is consistent with a highly warped and structured current sheet during solar maximum. We also note complexity in the periods that appear during the solar cycle 23 maximum. All of these features are interpreted in the context of warped current sheets and other periodically appearing structures.

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Fluvial Geomorphology

Timing and patterns of valley excavation within the Le Sueur River Valley, south-central Minnesota, USA

A combination of airborne LiDAR (light detection and ranging) and terrace dating through optically stimulated luminescence (OSL) and radiocarbon analysis are being used to create a conceptual model of changes in sediment excavation over time from lateral and vertical incision of the Le Sueur River valley in south-central Minnesota, USA. The river is responding to 65 meters of base level fall that occurred almost instantaneously at 11,500 radiocarbon years before present, when glacial River Warren carved the Minnesota River valley, leading to widespread incision on Minnesota River tributaries. As knickpoints moved upstream from the incised Minnesota River Valley, hundreds of terrace surfaces where formed. Terraces are being dated to better constrain the rate of valley incision. Initial observations indicate an initial rapid down-cutting. Other observations note the mid-Holocene dry period demonstrating a time of stability for the river valley. Results from this model will provide context for modeling efforts to understand current sediment fluxes out of the Le Sueur River in to the Minnesota and Greater Mississippi Rivers. It will also act as a case study in understanding how landscapes evolve in incising river systems.

In order to integrate my research in to the classroom I developed an activity based off of a student's question involving "how rivers get to places". Students used small stream tables to investigate what a landscape needed in order for a river to be created. I then introduced my research and explained to them that scientists will investigate landforms to help them understand how the river evolved in certain landscapes. This activity was part of a weekly series in which I create lessons using questions that students pose about the natural world.

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Applied Graphics and Technology

The Effectiveness of a Spatial Visualization Instructional Tecnology for Children with and without ADHD

Current research study hypothesize that the use of computer generated training as a method of instructional technology to enhance spatial ability is beneficial for students with and without ADHD and their resulting performance in geometry. To provide evidence supporting this theory, the authors are engaging in a study that will recruit seventh and eighth grade students with and without ADHD from local schools. This particular study will assess students' responses to two different computer generated training sessions – static and dynamic conditions. Both conditions include the same text, but differ in dynamic condition; the graphics that are associated with instruction are animated (moving), whereas the static condition includes graphics that are fixed. Preliminary findings and educational implications will be discussed.

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2-Dimensional Dynamic Systems

We use dynamic systems to mathematically model many aspects around us. A common model, which most people know about, is the use of a matrix to calculate the market shares two specific soft drink manufacturers will have after a certain amount of time has passed. This model is built upon the notion that the future can be predicted by values of the present. These models include only change in time. What if a specific place was not only dependent on the present state, but also by the state of an adjacent location? For example, the state of the water at a specific location in a river would be dependent on the state at that location at a previous moment in time. It would also be influenced by water coming down from a location upstream. We would need two matrices to model this type of behavior. One matrix for the mixing over time at a location, and one matrix describing the impact water upstream would have on a location downstream.
This is just one example where it would be to our advantage if it would be possible to use a dynamic system over two dimensions as our modeling tool. This research in progress addresses 2-D dynamic systems, and tries to derive formulas that could be used to model these systems.

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Quaternary Geology & Geomorphology

Late Pleistocene Lake Hubbs: Lacustrine chronology and geomorphology of Long Valley, Nevada, U.S.A.

Deep lakes occupied the Great Basin of western North America periodically during the Pleistocene. Long Valley, Nevada was occupied by Lake Hubbs during this period of increased precipitation and decreased temperature. Lake Hubbs occupied 195 mi2 of the 666 mi2 basin (Mifflin & Wheat, 1979). The highest shorelines of Lake Hubbs, Newark, Jakes, and Diamond have been identified as pre-late Pleistocene (Reheis, 1999), and an absolute age (14C) of 17,520 yr B.P. was determined for one lower Lake Hubbs shoreline (Young & McCoy, 1984). I hypothesize that, if driven by regional climate patterns, Lake Hubbs' transgressions and regressions are synchronous with the paleolakes of the central Great Basin. Ages for late Pleistocene shorelines exist for Newark's lower shoreline dated at 13,780 14C yr B.P. (Redwine, 2003), Jakes highstand and still-stand dated between 13,870 14C yr B.P. and 12,440 14C yr B.P. (Young & McCoy, 1984; Garcia, 2006), Diamond's highstand dated at 23,390 14C yr B.P. (Tackman, 1993), and Franklin's highstand between 16,800 and 15,070 14C yr B.P. (Lillquist, 1994), with little late Pleistocene data for Lake Hubbs. To explore this hypothesis, my thesis research includes: 1) mapping and identifying shoreline segments; 2) dating shorelines via radiocarbon (standard and accelerator mass spectrometry) and optically-stimulated luminescence; 3) interpreting stratigraphic and geomorphic evidence to determine transgression, regression, and still-stands of late Pleistocene/early Holocene Lake Hubbs. A more detailed study regarding the spatial and temporal extent of late Pleistocene/early Holocene Lake Hubbs is necessary to augment the understanding of paleoclimates that drive lake fluctuations and lake associated archeology of the area.

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Archeology

Sustainability of Arid Agriculture: Lessons for the Future from the Past

Archaeology provides a unique, long-term perspective on human interactions with the environment and case studies applicable for future environmental decision making. For my dissertation research, I am examining the sustainability of prehistoric agriculture in the semi-arid, Perry Mesa region of Arizona. The lack of adequate permanent water, low rainfall, and nutrient poor soils would have made farming the region difficult. Nonetheless, the region supported several hundred inhabitants from A.D. 1280-1425, indicated by the presence of dozens of prehistoric villages and a landscape extensively modified for agriculture. While ideas have been put forth as to why people initially settled the region, very little attention has been paid to why people left after this relatively short occupation. My research focuses on determining the role that climatic change and soil degradation played in the regional abandonment. I use an interdisciplinary approach to investigate these issues by integrating geographic information system analysis, paleoclimatic reconstructions, hydrology, soil ecology, population reconstructions, and estimates of agricultural carrying capacity. This research provides a long-term perspective on food production in arid regions as well as the consequences of climate change and degraded environments. These issues are increasingly important in the face of contemporary global climate change and the stresses to subsistence agriculture in other arid regions of the world.

Aspects of this research have been integrated into the K-12 classroom. I have discussed sustainability and carrying capacity using the concept of “ecological footprints” and have used my research as an example of how science answers questions using multidisciplinary approaches.

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Graphene Nanostructures

Nanoscale Graphene Lithography using Atomic Force Microscopy

A growing number of researchers are investigating the graphene material because of its exceptional electrical properties. Several techniques are available for nanoscale patterning of graphene, however these can be limited in speed, ease of use, or the range of patterns they can write. A precise and controllable voltage-applied Atomic Force Microscopy (VAFM) based local anodic oxidation lithography process for graphene patterning has lately been used to fabricate graphene nanodevices. This process has already been used to cut carbon nanotubes, machine holes in highly oriented pyrolytic graphite, and form insulating trenches in graphene layers.

In this work, we demonstrate use of the VAFM nanolithography process to pattern graphene nanostructures (<20 nm feature size). In this process, first, the AFM application conditions for local oxidation process parameters will be optimized. In humid atmosphere, the AFM tip and the graphene surface are covered by thin film of ambient water. When the tip approaches close to the surface, these layers come in contact and a water meniscus is produced by capillary effect. By applying the appropriate electric field, an electrochemical reaction in the tip-water-surface interface will be initiated through the meniscus. Applying a positive bias to the surface and negative to the tip, causes them to act as cathode and anode, respectively, and oxide will grow underneath the tip. Depending on such process parameters as applied voltage, pulse width, contact force, and humidity, the oxidation of graphene into volatile carbon oxides will enable the formation of trenches in graphene films - Figure 1. Figure 2 shows the preliminary result on a graphene sample.

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Environmental Science and engineering

Fecal Source Identification in Multi-Use Watersheds: A Novel Meta-Genomic Approach

Nearly 13% of the nation's rivers, estuaries, and lakes fail in meeting their designated uses as a result of increased levels of fecal bacteria from non-point fecal pollution sources. It is imperative to develop robust fecal source identification methods, as animal feces can introduce pathogenic microorganisms to waters used for recreation, public water supplies, and fish cultivation. To address this issue, we employed a novel meta-genomic approach to explore unique genetic attributes of fecal bacteria within several fecal and impaired environmental ecosystems. Our meta-genomic method has unveiled host-specific bacterial populations unique to cattle, swine, human, and avian hosts. Furthermore, several of these host-specific bacterial populations are also found in environmental waters, where the source of fecal contamination was known. Together our data indicate that these bacterial populations exhibit both host-specificity and environmental persistence, suggesting they are promising targets for fecal source tracking method development. Our research is stimulating the development of rapid, specific, and sensitive molecular detection methods which are able to discriminate amongst non-point sources of fecal pollution within multiple environmental monitoring scenarios in the United States. Reliable fecal source tracking methods will assist watershed managers in implementing appropriate management practices to protect our natural water resources from fecal contamination. Fecal source tracking integrates fundamental physical, chemical, and microbiological principles with novel molecular technologies, providing an opportunity for GK-12 students to understand how an interdisciplinary approach to research is essential in solving complex environmental problems.

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Cell Biology

Understanding the Signaling Mechanisms that Promote Cell Division

Cell division is the process that divides a single cell to form two daughter cells. In order for division to be successful, the cell must replicate and separate its chromosomes, and then it must physically divide between the separated chromosomes. The precise spatial and temporal control of division is critical to ensure that each daughter cell receives the correct number of chromosomes. The process of chromosome segregation is carried out by the mitotic spindle, a bipolar structure made up of microtubule filaments that connect to the chromosomes. In addition to its role in chromosome segregation, the mitotic spindle is also required to promote the final step of division, cytokinesis, which physically separates the two daughter cells. However, the specific mechanism by which the spindle promotes cytokinesis remains a mystery. In my work, I have found a novel role for spindle length in specifying the division site. During chromosome separation, the two poles of the spindle separate, and this separation is required mark a unique site for cell division. If the poles do not separate, then division will occur, but instead of having a single site for division, the cell will attempt to divide at multiple places along its length. The consequences of this type of division could be disastrous for the cell, suggesting that this mechanism is critical to ensure the integrity of the division process.

Although this type of research is difficult to bring into the classroom, I have been able to expose them to the model organism that I use, C. elegans. I have developed a number of activities that use this microscopic roundworm, and the kids have really enjoyed using a live organism to study things like transcription, translation, and neurobiology.

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Quantitative biology

A stochastic spectral analysis of transcriptional regulatory cascades

Cells process information using networks of interacting proteins. For example, information about a cell's position within an embryo (which ultimately determines the developmental fate of the cell) can be encoded in the abundance of a particular molecule that, either directly or through a chain of interactions, controls the production rates of the relevant structural proteins. Many proteins are present in low numbers (tens or hundreds per cell), which means natural fluctuations in their numbers can be on the order of the numbers themselves, i.e. their behavior is stochastic. Respecting this stochasticity with a mathematical model means solving for probability distributions over numbers of proteins. Traditional simulation-based approaches to computing probability distributions are fundamentally limited by long computational runtimes and the need to estimate distributions from samples. We obviate both limitations by directly solving for distributions using a fast and accurate method that exploits the natural basis of the uncoupled problem from the same class. We illustrate our method on a ubiquitous protein network: a simple linear cascade. The huge efficiency gains permit optimization of information transmission over input and regulatory parameters, revealing design properties of the most informative cascades.

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RF and analog integrated circuit design

Baseband CMOS Transimpedance Low Pass Filter for Multi-Standard Wireless Receiver Applications

The current trend in wireless receiver design is to develop multi-standard, low-power, highly integrated solutions, suitable for portable, battery-operated applications. However, multi-standard receivers experience signal integrity degradation that derives from the interference generated by other system blocks while operating simultaneously in different frequency bands. In consequence, this reduces the sensitivity of the receiver and increases the bit error rate of the communications system as a whole which is unacceptable. Signal degradation must be mitigated either by improving the performance of individual blocks in the analog front-end of the receiver, or through signal processing enhancements in the digital back-end, but the first choice is usually preferable since the latter is tied to the bit-resolution, dynamic range, and bandwidth of the analog-to-digital converter (ADC) and improving ADC performance is very challenging and costly. This work deals with the design and implementation of a baseband, transimpedance (TI) low pass filter (LPF) with enhanced interferer suppression, suitable for multi-standard CMOS receivers. By using active-feedback compensation, the response of the filter is modified so that a strong, out-of-band spectral interferer near the filter's cutoff frequency can be highly attenuated when present. Compared to a first-order TI LPF, our proposed solution increases the attenuation of an interferer by more than 20 dB. Using 0.18 um TSMC CMOS technology, transistor-level simulation results of our design verify its effectiveness in providing signal integrity protection while keeping cost, power, and area overheads low.

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Ecology

Developing an integrated socio-ecological model of dengue fever transmission

Emerging infectious diseases pose a heavy social and economic burden on human populations, particularly in developing countries. Dengue fever (DF), a virus transmitted to humans by the Aedes aegypti mosquito, is one of the most rapidly spreading viruses globally. With no vaccine currently available, an estimated 2.5 billion people in over 100 countries are at risk of contracting DF. The spread of dengue is poorly understood, but has been tentatively attributed to rapid urbanization, increased human migration, lack of mosquito control, and climate change. The ultimate objective of this research is to develop a dynamic, spatial model of Ecuador that integrates socioeconomic and climatic variables to identify populations at risk of contracting DF. In June 2008, a pilot study of dry season DF transmission was launched in Guayaquil, Ecuador, a coastal city with over 2 million people. The study identified socioeconomic factors that increase the risk for DF. Over 300 household surveys were conducted in two low-income communities; at each household, all mosquito pupae were collected and questionnaires were used to determine the history of DF infection, at-risk behavior, knowledge about DF, and household characteristics (e.g., screens on windows). Preliminary results suggest that DF transmission is sustained by water accumulation in human-made containers. Ultimately, this critical research will aid policymakers in mitigating DF epidemics.

I integrate my research into the classroom by guiding my environmental science students in developing independent research projects. I encourage them to venture beyond the typical boundaries of environmental science to conduct transdisciplinary research that they are passionate about and to incorporate an international perspective.

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Neuroscience

How Do We Learn? The Neuroscience of Learning and Memory

Within the brain, lies the ability to successfully learn and remember information. Patients with damage to an area in the brain called the hippocampus can no longer learn information following the incident of injury. Still able to retain memories of their past (e.g. childhood events), all new information is lost to these individuals (e.g. unable to make new friends or navigate a new city). They are, however, able to learn new skills yet have no explicit awareness of having done so. These results suggest multiple learning systems exist, whereby depending on the type of information processed a different brain area is recruited. Using a specialized type of MRI scan, we can measure changes in brain activity while individuals learn new information. Furthermore, we have the rare opportunity to record from single human neurons of neurosurgical patients monitored for epilepsy. While patients perform tasks, we are able to determine how neurons respond during learning. From these studies, we have found distinct areas in the hippocampus involved in learning, recollection, and integration of information.

High school chemistry students participated in a lesson on molecular structure. Students built molecules using modeling kits. A short lecture focused on chemicals in the brain, called neurotransmitters. Lesson culminated with an inquiry-based activity where students built molecular structures of neurotransmitters involved in learning and memory. CA standards 1a-b, 2 (Chemistry) and 2a-b, 3 (Content) were addressed. Lastly, in an effort to discuss how Neuroscience of learning might be incorporated in the classroom we held an event where neuroscientists, teachers, parents, and K-12 students came together to participate in discussions and hands-on activities on neuroscience topics.

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Geology

Development of Temperature-Sensitive Algal Compounds for Climate Reconstructions in Lakes of the Interior United States

Long chain alkenones are a class of temperature sensitive lipids with great potential for quantitative paleoclimatic reconstructions from continental locations. We have surveyed 57 lacustrine core-top sediments in the in the interior US for alkenones in order to constrain the environmental conditions that control the occurrence of alkenone-producing haptophytes in lakes and determine the possibility of using lacustrine alkenones to reconstruct temperature. Thirteen out of the 57 sites surveyed contain alkenones in surface sediments. Three of the 13 lakes contain abundant C37:4 alkenones as commonly found in lake sediments, whereas the rest of the lakes show a surprising absence of C37:4 alkenone. 18S Ribosomal DNA sequences amplified from the C37:4 containing lakes suggests the alkenone-producing haptophyte falls amongst the Isochrysis spp. and showcases a strong similarity to a haptophyte derived from Ace Lake, Antarctica, whereas the other lakes probably contain a different species. We also find that cold, oligosaline conditions with high concentrations of sodium and sulfate promote high concentrations of alkenones. The C37:4 alkenone is only present in lakes with salinity above 2.74 g / L. The alkenone index from sites with the C37:4 alkenone plot along a previously published temperature calibration. However, we present growth habitat information and a novel approach to create an alkenone temperature calibration using water column filters from Lake George spanning a temperature range of 8 to 24 degrees C. This calibration is applied to a short core record from Lake George, ND for the instrumental period (~120-yrs) and a high-resolution, Holocene-length record from Brush Lake, MT, in order to further assess the applicability of lacustrine alkenones.