CLIMATE MODULE

ARE HUMANS CAUSING CLIMATE CHANGE?

Week 1: Why is there a “Climate Debate?” How to interpret data

*Given a time dependent data, draw the best fitting line and apply this analysis to published data on Earth’s temperature variations to assess if climate is changing*

1. Given a time dependent data, make a data vs. time plot or given a time plot of a data, find the best-fitting line using spreadsheet software and comment on the quality of the data based on the correlation coefficient.
2. Given the findings of various studies, find the conflicting data and use them to make an argument for global warming.
3. Given the effects of parameters on the outcome of an experiment, be able to determine the correlation or causation between two parameters and calculate the correlation coefficient to determine the correlation degree between these parameters.
4. Describe the differences between the predator and prey models and the logistic growth model.

Week 2: The Earth has an “Energy Budget” that humans need to keep in balance

*Make general calculations on Earth’s energy balance and use data to describe the role of greenhouse effect in climate change*

1. List the types of radiation that affect the earth’s energy balance and compare their magnitude using the radiation spectrum.
2. Describe blackbody radiation, calculate the radiation from a given object and relate the blackbody radiation to the greenhouse effect.
3. Using the data on solar flux and albedo values, find the effective temperature of a given planet.
4. List the greenhouse gases in the atmosphere and explain what makes a gas a greenhouse gas.

Week 3: Atmospheric temperature rise seems to be mild, not because of the lack of climate change, but because of the warming of the oceans

*Relate gas laws to weather, differentiate between the components of the energy of a system and solve problems that relate the 1st law of thermodynamics to climate*

1. Describe the assumptions leading to the ideal gas equation of state, and explain why these are sufficient to explain the behavior of gases involved in climate science calculations.
2. Explain the terms in the van der waals gas equation and list the differences between ideal and van der waals gas laws in terms of the conditions for which they apply.
3. Calculate work done by or on a gaseous system from the area under the pressure-volume diagram and relate work done on a system and heat transferred to the internal energy of the system.
4. Describe what enthalpy is, differentiate it from internal energy, and reconstruct the relation between heat and enthalpy.
5. Discuss the effects of heat capacities of oceans and land on climate change.

**Week 4:** Does the climate change theory contradict the second law of thermodynamics?

*Make an argument on the relation between the 2nd law of thermodynamics and greenhouse effect.*

1. Identify “spontaneous” and “nonspontaneous” processes and infer that these are associated with entropy.
2. Calculate the changes in entropy of the system and the surroundings in the case of reversible and irreversible process by applying the relevant formulas.
3. Quantify entropy changes using a “statistical” approach by calculating the possible number of states (multiplicities) of the system and applying the Boltzmann Formula.
4. Explain entropy both from a macroscopic and a microscopic viewpoint.

**Week 5:** We can calculate if reactions producing stuff that lead to climate change will occur or not.

*Making informed decisions by relying on scientific results.*

*Identify Gibbs free energy as the quantity that defines the equilibrium state of a system, and give examples of situations where phase transitions affect climate change.*

1. Calculate the change in Gibbs free energy of the system from the changes in its enthalpy and entropy.
2. Predict whether or not a physical or chemical change is spontaneous given the temperature, from the Gibbs energy.
3. Identify the stable phase of a system, given its Gibbs energy vs. temperature/pressure graph.
4. Be able to sketch and discuss the implications of energy diagrams.

**Week 6:** Humans choose to burn fossil fuels not just because they generate a lot of energy, but also because they do it fast.

*Apply thermodynamic and kinetic arguments to climate related problems and how alternative energy resources may help solve them*

1. Distinguish between kinetic and thermodynamic parameters in a chemical or physical process.
2. Given a simple chemical reaction, find the reactants and products and derive the rate equation.
3. Using the rate constant and temperature data for a given reaction, calculate the activation energy.
4. Discuss the role of catalysts on the reaction rate and determine the rate limiting step of a reaction.

**Week 7:** Fossil fuels or alternative energy sources? Efficient engines are needed to convert any form of energy into useful energy.

*Construct P-V diagrams of simple heat engines and discuss how efficiency of engines is related to developing solutions to climate related problems.*

1. List, compare and contrast the benefits and downsides of at least three alternative energy resources.
2. Define efficiency of a heat engine and develop expressions for the efficiency of Carnot, Ericsson and Stirling cycles.
BRAIN MODULE

CAN WE EVER COMPREHEND THE WORKINGS OF BRAIN?

**Week 1:** How complex is the brain? How can we understand how it works?

**Discuss the properties of cells that constitute brain (neurons and glial cells), and describe how ions can diffuse across cell membrane**

1. Describe the features and functions of neurons (nerve cells) that distinguish them from other types of cells.
2. Compare the scales involved in our brain (number of networks, neurons, response time, etc.) with the numbers we are more familiar with (internet, computing power, etc.) to highlight the complexity of our brain.
3. Describe concept of flux due to macroscopic diffusion and relate it to the concept of concentration gradients.
4. Apply the Fick’s first law \( J = -D \frac{dC}{dx} \) to calculate the flux of ions diffusing across neuronal membrane in 1 dimension with a given concentration function.

**Week 2:** All cells maintain a potential difference to sense the world

**Explain the origin of resting membrane potential, relating to the concepts of potential energy due to electric charges of ions and their concentrations**

1. Relate Gibbs free energy to the spontaneity of diffusion and calculate change in the “chemical” potential energy due to diffusion.
2. Calculate electric potential energy of a system of charges in a constant electric field and the work done by the field.
3. Relate the ionic concentration differences and electric charge distributions to the establishment of membrane potential of a neuron, and calculate the electrochemical potential using Nernst equation.

**Week 3:** Information is communicated in neurons through electricity: Action potential

**Using the concepts of diffusion and membrane potential, describe how electrical signal is generated within a neuron (action potential), and how it can be modeled with an electric circuit.**

1. Describe the mechanism of electric signal (action potential) formation in a small patch of neuron membrane by relating it to the electric field, potential across the neuron membrane, and ion diffusion
2. Compare and contrast the components of neuron membrane and a simple RC circuit model of the membrane patch
3. Relate the concepts of resistance to modeling of the cell membrane by describing how ion channels can regulate ion current
Week 4: Neuronal cell membrane can be mathematically modeled by simple circuits

*Explain the sequence of neuron communication (stimulation and action potential) and discuss the factors affecting the signal propagation time based on the circuit model*

1. Relate the concepts of capacitance to modeling of the cell membrane by describing how capacitance of the membrane change during an action potential.
2. Model an action potential using the concept of resistors and capacitors and relate the time constant in the RC circuit to the action potential model.
3. Describe how the action potential travels along the neuron axon using the concepts of the space (length) constant in the circuit membrane model.
4. Given the time constant and space constant, estimate the signal transmission speed within a given neuron using the RC circuit model.

Week 5: How do neurons work together? Neural network and connectivity

*Relate the single neuron circuit to neuron communications and explain how neural network functions*

1. Evaluate the factors affecting the speed of the signal transmission.
2. Compare and contrast “myelinated” and “un-myelinated” axons, using the concepts of time constant and space constant.
3. Apply the concepts of passive transport mechanisms to explain how a neuron communicates with another neuron through synaptic transmission.
4. Relate electric and chemical potential energy concepts in active membrane transport mechanisms (Na/K pump).

Week 6: How can we measure brain activity and interpret the data?

*Discuss various ways of measuring brain anatomy and activities, and data interpretations*

1. Compare and contrast various brain activity measurement techniques and their use, and create an appropriate hypothesis that can be tested by one of the techniques.
2. Discuss how same data can be interpreted differently based on the threshold values applied, and illustrate how it could give rise to false scientific claims.
3. Design or revise a simple experiment based on the scientific method, to probe a certain brain function.

Week 7: How does brain function and how does our mind work? Inner workings of brain and cognitive science

1. Relate single neuron circuit model to the web of neural circuit to explain how animals function.
2. Summarize how neurons in different parts of the brain communicate and make long-lasting connections.
3. Discuss why we are yet away from understanding very-complicated workings of our brains.