Integrated STEM Environmental and Biological Sciences

Introduction and Overview

Units 1-5 build basic skills in electronics, programming, data acquisition and analysis, constructing explanations and making simple models. Units 2 - 5 each include simple experiments to be performed by the students. More in depth experiments are constructed in Units 6-8, 9-11, and 12-13. For each major experiment (heat diffusion, organism growth and environmental effects on biological systems), students are engaged in the complete life cycle of an experiment that spans all 8 NGSS goals as summarized below:

1. Asking questions (for science) and defining problems (for engineering) – see units 3, 4, 5, 6, 9 and 12.

2. Developing and using models – see units 3, 4, 5, 8, and 11

3. Planning and carrying out investigations – see units 3, 4, 6, 9, and 12

4. Analyzing and interpreting data – see units 3, 4, 5, 6, 9, and 12

5. Using mathematics and computational thinking – see units 2, 3, 4, 8, and 11

6. Constructing explanations (for science) and designing solutions (for engineering) – see units 3, 4, 5, 7 and 10

7. Engaging in argument from evidence – see units 7, 10 and 13

8. Obtaining, evaluating, and communicating information – see units 7, 10 and 13

Unit 1: Introduction to the computer and keeping laboratory notes

In Unit 1, students will be introduced to the computer that will be used for all subsequent work in the class. Students will learn how to turn on the computer, and use the terminal window to run programs. They will also learn how to use the text editor, including elements of file copying, naming and editing. Students will also learn how to use the web browser on the machines provided.

Students will be assigned to write a laboratory report using the text editor. (Students will be required to keep a laboratory notebook that documents their work throughout the course.) They will also copy and rename the file, placing it in an indicated location within the file system.

By the end of Unit 1, students will be able to demonstrate proficiency navigating within the file system and using the web browser and the text editor to create documents.

Unit 2: Computational Thinking and Geometric Explorations using Logo

In Unit 2, students will be introduced to the Logo programming language using Turtle Logo. Turtle Logo can be used to draw on the computer screen while demonstrating rudimentary computational thinking concepts such as looping and conditionals. Students will be assigned to create original Turtle Art using their own choice of shapes and colors. At least one loop must be included in their Turtle Logo program.

By the end of Unit 2, students will demonstrate proficiency in understanding simple programming constructs and will create an original Turtle Art design using geometrical shapes.

Unit 3: Investigating Energy and Charge in Electronic Circuits

In Unit 3, students will be introduced to breadboards and will wire the power and ground for their own breadboards. They will learn how to use a digital multi-meter to measure current, resistance and voltage, and will build a simple analog circuit that uses a battery and a resistor. Students will be assigned to modify the simple circuit to include an additional resistor in either parallel or series with the battery. They will draw the circuit schematic and make predictions for the voltage to be measured across each resistor. They will then measure the voltages using digital multi-meters and will record and report the results. Students will be assigned to modify the simple circuit to include an additional resistor in either parallel or series with the battery. They will draw the circuit schematic and make predictions for the voltage to be measured across each resistor. They will then measure the voltages using digital multi-meters and will record and report the results. The unit will progress with series and parallel circuits. Students will plan and carry out investigations around voltage, current, resistance. They will then analyze and interpret the data from the readings, and draw conclusions about Ohm's law.

By the end of Unit 3, students will be able to measure voltages in simple circuits and will construct explanations that relate their measurements of current, voltage and resistance (Ohm's law).

Unit 4: Measuring Heat and Temperature

In Unit 4, students will be introduced to the circuit boards that comprise the hardware platform for the Learning by Making experiments. They will learn how to hook the boards up to the computer and how to use them to acquire data from a temperature sensor. They will also learn the basics of analog to digital and digital to analog conversion.

Students will be assigned projects in which they use Logo to acquire sensor data, either from more than one sensor, or at a different cadence with a single sensor. Students will learn how to calibrate temperature sensors by planning experiments to compare the sensors to thermometers. They will also investigate how heat is dissipated in resistive materials that are carrying current.

By the end of Unit 4, students will demonstrate that they can correctly wire a circuit using the breadboard, at least one temperature sensor and the Learning by Making circuit boards. They will also be able to relate the voltages produced by temperature sensors to physical temperatures, and will be able to construct explanations and simple models to explain resistive heating.

Unit 5: Analyzing, Interpreting and Evaluating Light Intensity Data

In Unit 5, students will learn how to analyze and display data using the Logo programming language. They will learn how to process measurements to increase signal to noise and will use simple statistics (mean, median, etc.), linear regressions and plotting and graphing techniques. They will also learn how to plot the output of more than one sensor on the screen, how to save their data and plot files for later analysis, and how to calibrate a sensor so that plots display physical units (not the output of the A/DC readout).

Students will plan and carry out investigations into the relationship between light intensity and distance. They will analyze their data by plotting graphs in order to determine the mathematical ($1/r^2$) relationship. They will plan and carry out investigations into the linearity of their temperature and light sensors, and compare these relationships to those determined by other students. They will explore the limitations of the provided temperature and light sensors and analyze their suitability for potential future experiments.

By the end of Unit 5, students will be able to modify the provided Logo code to customize the graph formats, to include additional statistical analyses, and to provide graphs in physical units. They will have characterized their sensors, and will construct explanations and simple numerical models to explain their measurements of the intensity of light as a function of distance.

Unit 6: Investigating Heat Diffusion

In Unit 6, students will learn about the heat diffusion experiment. This experiment uses a relay-controlled light bulb, a bucket of sand or other heat conducting material, and temperature sensors placed at specified depths. They will learn how to control the light on/off cycle, to read out the temperature sensor, and to analyze and display the data in real time as the experiment runs through many cycles. After studying the heat diffusion experiment, students will be asked to think through the physical scenario that is being represented and to pose a question that can be investigated using modifications of the experiment. They will predict the behavior of the temperature sensor(s) prior to running the experiment and will then plan and carry out these investigations. Examples include: changing the depth at which the sensor(s) are located, adding additional sensors at different depths, changing the cadence of the light on/off cycle, changing the heat conducting material, etc. Student teams will then run the modified experiment with support from the instructor, as well as from other students. This will be an iterative process as the results will not be known (to the students) ahead of time.

By the end of Unit 6, students will have learned about the lifecycle of a complicated experiment and will have planned and carried out their own investigation. They will demonstrate proficiency in their understanding of the core ideas, mathematics and skills that have been learned through the semester including: programming Logo, electronic design, wiring and circuit debugging; sensor measurements and calibration; data acquisition and regression analysis; graphical data display and real time plotting.

Unit 7: Constructing Explanations and Communicating Results of the Heat Diffusion Experiment

In Unit 7, students will summarize their individualized experiments and present their hypotheses and results to their peers and instructor. They will discuss experimental design flaws and successes and present an argument based upon the evidence that they have collected as to the validity of their hypotheses. They will construct explanations as part of the comparison of their predicted results to the actual measurements, analyze problems with their experimental implementation and discuss methods that could be used to improve the experiment in the future. Students who are not presenting will provide feedback/input to students who are presenting, switching roles between presenter and reviewer as the different groups take turns reporting their results. The student presentations are the assignment for this unit. Students will create the presentations, including schematics of their design, explanations of the computer code they generated in order to run the experiment, calibrate, acquire, analyze and display the data, and they will show the resulting plots and statistical analyses.

By the end of Unit 7 and in the context of the heat diffusion experiment, the students will have demonstrated that they can construct explanations, argue from evidence, evaluate results and communicate these results to others.

Unit 8: Modeling the Heat Diffusion Experiment with Real World Extensions

In Unit 8, students will improve their coding skills as they learn more sophisticated programming techniques, including loops, conditionals, logic constructions and numerical difference methods. They will model the heat diffusion experiment using random particle diffusion to represent heat flow. Programs written by the students will also plot the heat flow with different types of initial conditions, and the plots will be compared to the actual data obtained from the heat diffusion experiment to derive the numerical relationships between time and distance. Students will understand that diffusion is an example of a scaling relationship, and they will investigate how scaling can relate their results to temperature profiles of boreholes that are drilled in the Earth.

By the end of Unit 8, students will demonstrate that they can program simple diffusion models and can scale the results of their models to real-world situations.

Unit 9: Investigating Organism Growth in a Microbial Fuel Cell

In Unit 9, students will pose questions and then plan and carry out investigations using microbial fuel cells. These investigations into organism growth will use transparent containers, anode and cathode materials, a light source, heaters and temperature sensors. They will use previously learned skills to read the temperature sensor and use temperature data in a feedback loop to control a heater needed to optimize (or impair) the conditions for organism growth. Growth will be measured by recording the voltage from the microbial fuel cell. Students will analyze and display average measurements of the voltage data as the experiment runs through many days. When the experiment has been successfully implemented, students will be asked to think through the factors that have affected the organism growth rate. They will then plan and carry out an additional investigation for which they will predict the organism growth rate. Examples include: changing the temperature at which the culture medium is held, changing the substrate containing the organisms, adding additional nutrients, etc. Student teams will then work through these experiments with support from the instructor, as well as from other students. This will be an iterative process as the results will not be known (to the students) ahead of time.

By the end of Unit 9, students will have successfully implemented an individualized extension experiment that includes all the core ideas, mathematics and skills that have been learned in this unit including: exponential functions, programming feedback loops, and the biological conditions for organism growth.

Unit 10: Constructing Explanations and Communicating Results of Organism Growth Experiments

In Unit 10, students will summarize their individualized experiments and present their hypothesis and results to their peers and instructor. They will discuss experimental design flaws and successes and present an argument based upon the evidence that they have collected as to the validity of their hypothesis. They will construct explanations as part of the comparison of their predicted results to the actual measurements, analyze problems with their experimental implementation and discuss methods that could be used to improve the experiment in the future. Students who are not presenting will provide feedback/input to students who are presenting, switching roles between presenter and reviewer as the different groups take turns reporting their results. The student presentations are the assignment for this unit. Students will create the presentations, including schematics of their design, explanations of the computer code they generated in order to run the experiment, calibrate, acquire, analyze and display the data. They will also present the resulting plots and simulations.

By the end of Unit 10, and within the context of the organism growth experiment, the students will have demonstrated that they can construct explanations, argue from evidence, evaluate results and communicate these results to others. They will have worked through the complete life cycle of a second individualized experiment, and they will be able to synthesize environmental and biological concepts.

Unit 11: Modeling Organism Growth with Real World Extensions

In Unit 11, students will learn how to model population growth using exponential functions. They will write programs that can model the growth rates of their organisms as measured in individual experiments from Unit 9 and will compare the simulated results to their own data. They will also learn how to extend population growth models to situations in which two populations are competing for limited resources, and also where one population feeds on the other.

By the end of Unit 11, students will demonstrate that they can model growing, competing and decaying populations. They will use mathematical and/or computational representations to support explanations of factors that affect the carrying capacity of ecosystems at different scales and will show how their experimental results scale to real world ecosystems.

Unit 12: Investigating Environmental Effects on Biological Systems

In Unit 12, students will plan and carry out one of three possible environmental measurements: air quality, water quality or radiation environment. They will construct an experiment for their chosen measurement and pose questions informed by online resources that describe the biological effects of decreases in air quality, water quality or the effects of increased ionizing radiation on biological systems. When the initial experiment has been successfully implemented and analyzed, students will be asked to think through the factors that have affected their measurements of air quality, water quality or radiation environment. They will then compare their local results to measures of air quality, water quality or radiation environment in available databases from other parts of the world.

By the end of Unit 12, students will have measured an environmental quantity that has a direct impact on biological systems, and they will gain a global perspective on how local measurements compare to conditions in other parts of the world. For example, they can compare local air quality to published measurements in China, local water quality to published measurements of polluted waterways, or local radiation measurements to areas in Japan or Russia with radiological contamination.

Unit 13: Constructing Explanations and Comparing Results of Environmental Effects on Biological Systems

In Unit 13, students will summarize their individualized experiments and present their questions, hypotheses and results to their peers and instructor. They will discuss experimental design flaws and successes and present arguments based upon the evidence that they have collected as to the validity of their hypotheses. They will analyze problems with the experimental implementation and discuss methods that could be used to improve the experiment in the future. Students who are not presenting will provide feedback/input to students who are presenting, switching roles between presenter and reviewer as the different groups take turns reporting their results. The student presentations are the assignment for this unit. Students will create the presentations, including schematics of their design, explanations of the computer code they generated in order to run the experiment, calibrate, acquire, analyze and display the data, and show the resulting plots and simulations. They will also investigate the relationship between environmental quality and measures of human health (e.g., specific environmentally related diseases, measures of longevity, etc.) by comparing local conditions and health measures to similarly measured quantities in other parts of the world.

By the end of Unit 13, and in the context of the environmental quality experiment, the students will have demonstrated that they can construct explanations, argue from evidence, evaluate results and communicate these results to others. They will also have integrated environmental and biological information and will demonstrate their understanding of the relationships between the management of natural resources and the sustainability of biological populations.