# Development and Implementation of Real-Time Wireless Sensor Networks for Data Literacy Education

**Jody Clark[1], Wil Falkner[2], Ron Ratkos[3], Sarthik Balaji Kuruvadi[2], Daniel Bruce[2], William Zummo[2], Kumar Yelamarthi[2]**
[1]Chippewa Hills High School, Remus, MI
[2]College of Science and Engineering, Mt Pleasant, MI
[3]Mid Michigan Community College, Harrison, MI
yelam1k@cmich.edu

*Abstract*

The current requirements of industry and the ubiquitousness of the information age have demanded a profound change in the focus of public education. Although public schools have historically addressed the needs of science and math adequately across the curriculum the more recent STEM (Science, Technology, Engineering, and Math) movement and its many submovements (STEAM arts, STREAM reading, STEMM medical) have often been found lacking in their use of engineering principles and engineering's relevant, developing technology. This problem is exacerbated by the rapid changes in both technology and information systems which tend to leave the quickly outmoded and financially strapped education systems behind in their wake. Through RET(Research Experience for Teachers) grants, science and math teachers are given authentic engineering research experiences and tasked to develop a curriculum that incorporates the principles used in their research into their lessons. The six-week summer RET program located at Central Michigan University in Mount Pleasant, Michigan has for the past 5 years allowed secondary and postsecondary teachers to utilize microprocessors and sensors in an effort to initiate engineering-based learning experiences in their STEM classroom. It is through this grant that the Lab-in-aBox was developed.

The lab in a box is a STEM technology device combining Arduino Microprocessor and various sensors to collect the available data around you. It was designed and built using various engineering concepts such as 3D printing (printing the Box), AutoCAD (design), and various software such as Arduino, ThingSpeak (Cloud Server), MQTT, and TCP/IP. These are something students all over the world are looking into and collecting the data through sensors like the light sensor, motion sensor, pressure sensor collect and analyze the data for various purposes.

## I. Introduction

The current requirements of industry and the ubiquitousness of the information age have demanded a profound change in the focus of public education. Although public schools have historically addressed the needs of science and math adequately across the curriculum the more recent STEM (Science, Technology, Engineering, and Math) movement and its many sub movements (STEAM *arts*, STREAM *reading*, STEMM *medical*) have often been found lacking in their use of engineering principles and engineering's relevant, developing technology [1]. This problem is exacerbated by the rapid changes in both technology and information systems which tend to leave the quickly outmoded and financially strapped education systems behind in their wake.

Modern education is also challenged by rapidly advancing technologies such as online coursework, digital formats, mobile learning, and one-to-one technology in the classroom. These new methods of discovering information negate the need for modern educators to be the source of facts which now can be quickly accessed on the web. With this in mind, older paradigms of teaching are slowly giving way to the project and problem-based formats called for in the newer Common Core Math and Next Generation Science Standards. These changes require science and math teachers trained to incorporate problem-solving techniques and the inherent aspects of the engineering and design process they evoke into their lessons (Rockland et al., 2010). The lack of proper training in these newer pedagogies has stymied the authentic implementation of current standards, resulting in less E in STEM. Programs such as the National Science Foundation's Research Experiences for Teachers (RET) have been initiated to remedy this situation.

Through RET grants, science and math teachers are given authentic engineering research experiences and tasked to develop a curriculum that incorporates the principles used in their research into their lessons. The six-week summer RET program located at Central Michigan University has for the past 5 years allowed secondary and post-secondary teachers to utilize microprocessors and sensors in an effort to initiate engineering-based learning experiences in their STEM classroom. It is through this grant that the Lab-in-a-Box was developed.

The Lab-in-a-Box uses inexpensive STEM technology combining an Arduino microcontroller and various compatible sensors that are making their way into classrooms and after-school programs. Many math and science students nationwide are beginning to use various devices such as the Raspberry Pi and Arduino combined with motion sensors, light sensors, and pressure sensors to collect and analyze data for a variety of purposes. These new technologies are natural springboards for implementing engineering design into the mix. Using all these technologies Lab-in-a-Box was developed.

A lab in a box is a portable sensor platform that monitors the indoor environment. This is a low cost, a battery-powered sensor which is light in weight and easily portable and can be installed anywhere. This lab in a box can establish high volume data communication with the help of a WiFi compactable microprocessor which supports and transmits data faster than wired communication. In order to make the collected data more accessible and readable, a central database server has to be created. The central database server will help in collecting and storing the communicated data collected from all the sensors in the form of graphs. This also provides easy access to end users while also presenting graphics for quick identification of trends. The main components involved in Lab in a box for collecting and measuring, and storing the environmental readings and data include sensor devices, microprocessors, and a central database server.

The lab in a box establishes unfailing high-volume communications with the help of an inbuilt Wi-Fi on the microprocessor. The central database server is a single server designed to receive and efficiently store the data collected by all the attached sensors network. The central database server also provides easy access to the end user with customizable graphing and raw data access with a robust security model to address concerns of data privacy.

By connecting the power supply and running the code, Lab in a Box starts collecting the data and forwarded to the central database server. The close-up picture indicates the case is 3D printed to ensure proper functions of the sensors and easy enough to attach to the interior surface.

Figure 1: Lab in a Box with the ultrasonic sensor, temperature sensor, light sensor, microprocessor, and power supply.

The Lab-in-a-Box was developed using the shared software available for these devices. Educators are now realizing the industry's growing need for people skilled in computing languages such as those used with these microprocessors. Even elementary students are beginning to create computer code with online tutorials such as The Hour of Code [2] and scratch [3]. Robotics clubs and similar afterschool programs have embraced and implemented computer programming STEM principles which have allowed schools to take computer science to a new level. Unfortunately, the need for materials and technology required to implement more programs like these has been hampered by the lack of public school funding. It is hoped that inexpensive modules such as the Lab-in-the-Box and the engineering-based lessons that can be built around it may be helpful in remedying these issues.

## II. STEM, NextGen, and Data Literacy

The Next Generation Science Standards (NGSS) include nine science and engineering practices such as ‘analyzing and interpreting data,’ ‘using mathematics and computational thinking,’ and ‘obtaining, evaluating, and communicating information’ which all may refer to specific data science proficiencies. However, many uses of data in K-12 classrooms involve student-collected data of relatively small size. To prepare students to perform these science and engineering practices on larger, more complex data sets, new tools for gathering such large, complex data sets are needed. Sensors in the classroom such as those found in the Lab-in-a-Box can allow students to collect large amounts of data in a relatively short amount of time [4]. These sensor-created datasets would give students experience in handling large data sets and using more advanced statistical analyses than typically reached in a STEM classroom.

Another emerging trend in STEM education is the necessity for data literacy despite the lack of specific K-12 data literacy standards. Data literacy is defined as the ability to use large datasets to solve real-world problems [5]. As technology advances, data is becoming more common, larger in size, and more complex to understand. Therefore, education must rise to the occasion to prepare students to deal with future data demands beyond simply reading charts and descriptive statistics. Numerous attempts have been made to list data literacy standards, but Wolff et al (2016) states it in terms of real-world applications: communicators (interpret data to tell a story), readers (interpret data presented in day-to-day life), makers (curation of data sets to solve real-world problems), and scientists (blending data skills with content knowledge to explain phenomena). A further dimension includes awareness of data ethics, real-world problems that can be solved with datasets, and usage of a data lifecycle similar to a scientific method or engineering design process.

III. Design and Implantation

Students are well connected with technology. This technology can be used to teach math and science. One such Technology is called Wireless Sensor Network (WSN) and the Internet of Things (IoT)

IoT: IoT refers to a global network of objects, or "things", seamlessly connected to the internet which can fundamentally shift the way we interact with our surrounding. This IOT enables physical objects to see, listen, think, and perform tasks by sharing information and coordinating decisions. IOT transforms objects from being traditional to being smart by exploiting its underlying technologies such as sensor network, embedded devices, communication technologies, and ubiquitous and pervasive computing. Some architecture components of IOT are sensors, microprocessors, gateway, cloud, actuator, wired/wireless communication.

Sensors: A sensor is a device whose purpose is to detect information or changes in its environment and send information to a computer or a microprocessor. Different types of sensors are ultrasonic sensors, moisture sensors, motion sensors, light sensors, temperature sensor etc. The information given out by a sensor is not human readable not understandable. The information given out by the sensors has to be decoded, and to decode this information we need a microprocessor.

Microprocessor: A microprocessor is a computer processor that incorporates the function of a central processing unit on a single integrated circuit. Some microprocessors are Adafruit Huzza8266, Adafruit trinket, Adafruit Uno, Adafruit Mega and many more.

Communication: As the microprocessors are low power, there should be high computational capability. The information is then sent to the cloud wirelessly. When data is transmitted from a sensor to a microprocessor it has to be a wired communication. It can be UART, $I^2C$, and SPI.

Gateway: A physical device or a software program that serves as the connection between the cloud and the sensors or the controllers.

WSN/IoT is a combination of various sensors, microprocessors, and clouds. They work wirelessly to interact with the surrounding and physical objects to collect data and send the collected data to the cloud so anyone can subscribe to the published collected data.

Here Adafruit Feather Huzza8266 was used as our microprocessor, ThingSpeak as the Cloud and various sensors such as a humidity sensor, temperature sensor, distance sensor, or light sensor. The humidity sensor can sense the humidity in the atmosphere, the temperature sensor can detect the temperature both in Fahrenheit and Celsius, the ultrasonic sensor can be used to calculate the distance between the object and the sensor, and the light sensor can detect the amount of light in the atmosphere.

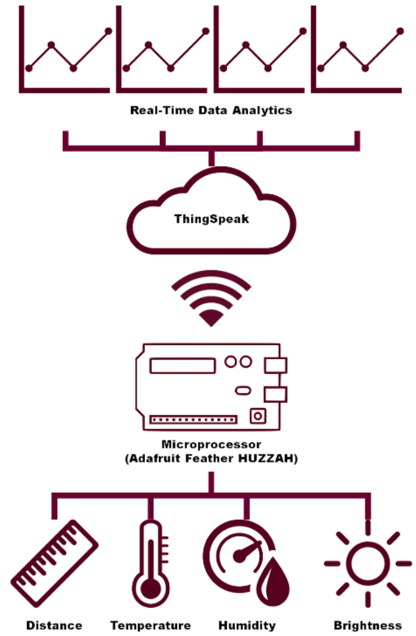

Figure 2: Modular IoT Architecture

*Wireless Sensor Network / Internet of Things*

When any of these sensors are used to collect the data using Huzza8266 as our microprocessor, the collected data can be sent to ThingSpeak. The easiest way to send data to ThingSpeak is to use TCP/IP. TCP/IP allows publishing data received from MQTT server. This gateway allows easy access to the IOT world and they are compactable with IoT server that supports MQTT. As the Huzzah is compatible with a built-in Wi-Fi and can send data to the cloud (ThingSpeak) without any other help. Sending the data to the cloud can be done by using an Adafruit Huzzah as our microprocessor. When using an Arduino, the Wi-Fi credentials can be added to the code, with the help of Adafruit.io dashboard the data can be stored at the dashboard. Therefore, the data being collected at the dashboard can be sent to ThingSpeak using MQTT. The reason for choosing MQTT is, when a connected device sends data to a server, any cloud with API keys can take the data. A connected device should function and should be controlled. These devices are typically behind the firewall. The firewall does not allow inbound connections, making it possible to connect to a device from outside. This is the point where HTTP protocol does not provide any standard mean of exposing restful functionality to the outside world. MQTT does, Web Socket and IOT protocol do not. A device connects to the MQTT server can subscribe to topics, and anybody with the right credentials can also connect to the same MQTT server and publish message

Wireless Sensor Networks (WSN) and the Internet Of Things (IoT) work hand in hand. These wireless technologies interact with physical objects in their surroundings through various sensors and publish collected data to cloud servers such as ThingSpeak. Once this data is on ThingSpeak it can be analyzed and interpreted to solve real-world problems. In creating the Lab-in-a-Box, the Adafruit Feather HUZZAH with ESP8266 (Feather) microcontroller was utilized to connect a humidity and temperature sensor (DHT-11), an ultrasonic sensor (Ping-28015), and light sensor (GL5528) to ThingSpeak. Data from the sensors are initially compiled by the Feather and then directly sent via WiFi to ThingSpeak utilizing HTTP (Hypertext Transfer

Protocol) and TCP/IP (Transmission Control Protocol/Internet Protocol). This is done by TCP securing a connection between two devices and HTTP using this connection to transfer data between the client and the server.

## IV. Results and Discussions:

Throughout the project, numerous errors occurred but these also became the best points of learning. The errors can be simplified into three categories; the poor connection between electrical components, malfunctioning sensors, and improper code. The lesson learned from a malfunctioning sensor is the issue could be in the hardware itself, not the design or the code. One of these problems was the ultrasonic sensor giving the reading of 0 (indicating no distance) or an extraneous distance value (greater than two meters). To resolve this issue the parallax ultrasonic sensor, a more expensive and updated device was used to replace the original HC-SR04 ultrasonic sensor. This is an easy fix and should be one of the first things to check when errors arise. To check this each sensor was separately run with only its code on the feather. Once all the sensors were known to be working, they were integrated together.

Another lesson learned was that without a proper connection the data cannot be read, even from a properly working sensor and microcontroller. This issue was faced when all the code was working properly the previous day, but would not run the next time. The next logical step was to believe it was a connection error, and changing the jumper cables from the Feather to the ultrasonic sensor solved the problem.

Struggles with code errors were the most prominent problem and led to many small learning lessons on how code functions. The code used was taken from Github (github.com), a website full of software repositories. Adafruit, the maker of the Feather intentionally puts its code on Github as a way of allowing others to access it. There was an issue because the code was designed for other projects and modified to fit the Lab-in-a-Box. Despite most of this code is reliable, there were issues. The code writing the data from the ultrasonic sensor to ThingSpeak had numerous errors connecting to the internet and the cloud server. There were errors in the imported libraries and the loops in the code. This led to breaking down the code systematically in order to learn the function of each command. This was difficult in the beginning, but with help from ThingSpeak tutorials and internet searches the code was functional. The lesson learned here to not reinvent the wheel. Reinventing the wheel would have entailed rewriting the code from the beginning and since it was possible to use the existing code with tweaks, a lot of time was saved.

Numerous amounts of data were collected with the help of all the sensors and stored in the central database server. The data collected is stored in the form of graphs for easy understanding and analyzation of the data. The figure below illustrates how the data is stored.

## V. Data Science Lessons Utilizing Lab-in-a-Box

Three envisioned lessons were developed, placing them in three different settings; middle school, high school, and college. Each lesson utilizes lab-in-a-box as a data collection device for students to handle and analyze. Standards and performance expectations aligned with NGSS and CCSS are listed at the end of each lesson module. The first lesson is a high school algebra challenge dealing with the modeling of large datasets streamed from the Lab-in-a-Box. In the second lesson, middle school science students are tasked with using environmental data from the

Lab-in-a-Box to secure a niche for an organism given it's bIoTic and abIoTic needs. Finally, an introduction to data science laboratory exercise for elementary education students is introduced to incorporate elements of inquiry and STEM.

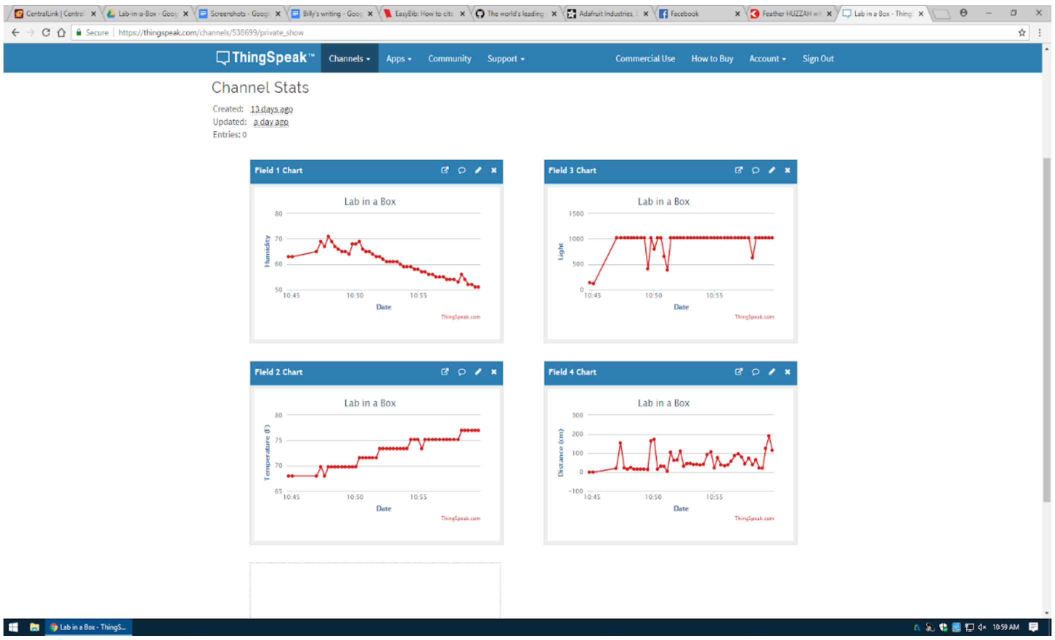

Figure 3: This figure illustrates how the data collected from Lab-in-a-box is stored in the central database server.

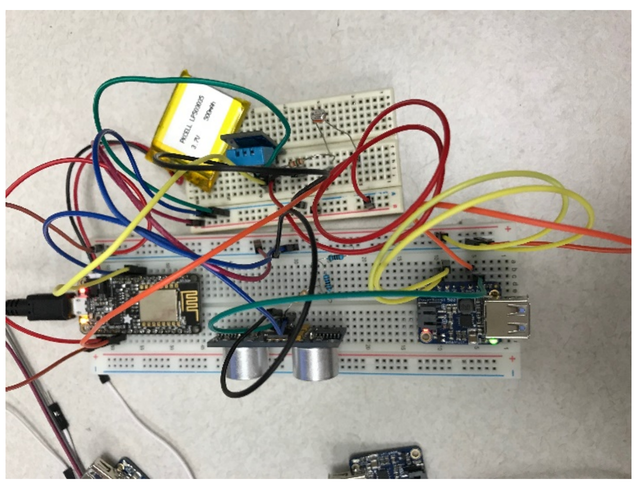
Figure 4: Lab-in-a-box with wire technology to collect data in the initial day of the project

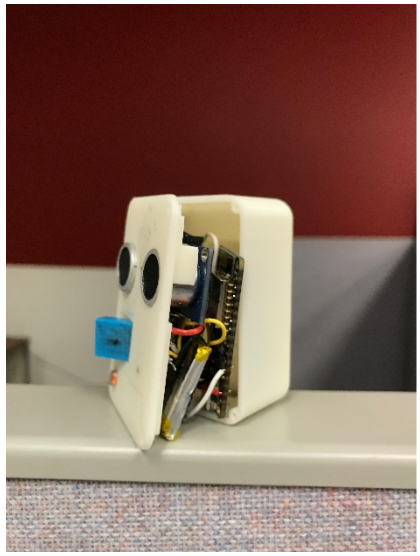

Figure 5: The Lab-in-a-Box made with minimal wiring and data is being transmitted using wireless technology

*High School Algebra: Graph the Story*

One lesson has been developed for a high school algebra 1 class during a unit on functions. Individual teams consisting of 3-4 students will utilize data collected from a Lab-in-a-Box to analyze graphs. The Lab-in-a-Box will be randomly placed in the classroom and allowed to collect data for several hours. Graphs of temperature, humidity, light and motion data generated from the Lab-in-a-Box will be accessed from ThingSpeak, a cloud-based server for students to analyze. Key features of the graphs will be assessed by each team and relative real-world scenarios as to why and when changes in the data occur will be discussed. Following the discussion, each student team will develop a story from the graph of data collected from one particular sensor. Each group will be required to use the correct labels and units on the graph used to help create their story.

In addition to creating stories from real-time Thingspeak graphs, students will be asked to create graphs from hypothetical stories that describe changing sensor data. An example is a case where a hypothetical Lab-in-a-Box is placed in the room where the temperature is rising at a constant rate (near a heat source). Other hypothetical Lab-in-a-Box modules will be "placed" in areas where similar changes in data are occurring. For example 1. an area with a person pacing past the ultrasonic sensor, 2. rooms where the lights go off after a specific time period and 3. an area where the humidity is being altered. Groups of 3-4 students will collaborate to create graphs of each sensor's data over time. Each graph will identify the changing variable and use appropriate labels and units to track changes. Groups will then present their graphs to the class pointing out key features as to how they needed to adjust for the variable sensor data.

One of the common core math standards that are addressed in this lesson is HSF.IF.B.4. Students are interpreting key features of functions that model a relationship between quantities (CCSS 2010). In this case, they are looking at a temperature over time, light intensity over time, humidity and distance over time. In addition, students will be a given a scenario that would cause the sensors to give variable data. The students will create a graph of their data and identify the key features of the graph. Another standard that is included in this lesson is HSN.Q.A.1, students are choosing and interpreting scale and origin in their graphs (CCSS 2010). HSN.Q.A.2 is also utilized because when students are creating a story to match a graphical representation numerical quantities will need to be addressed in the story (CCSS 2010). Standards for mathematical practices are also incorporated into this lesson. Students will be modeling with mathematics by creating graphs from stories. By taking a story and creating a graphical representation, students will be reasoning abstractly and quantitatively (CCSS 2010). Table 2 below lists all of the standards that are included in this lesson.

## VI. Middle School Life/ Environmental Science: Where's Home?

One scenario envisioned for a middle school life/ environmental science unit is to utilize the Lab-in-a-Box to generate data for habitat consideration. Multiple Lab-in-a-Box modules will be set up in different areas of the middle school science classroom. The instructor will attempt to select areas with varying temperatures, humidities, and light intensities so as to give a broad range of possible habitats for a predetermined organism. The organism can be real or created in response to the typical parameters of that particular classroom. An example would be a rainforest floor plant which demands high temperatures and humidity but does not allow for high light exposure.

The students will study the bIoTic and abIoTic criteria for the selected organism and begin to model preferred habitats and environmental considerations for that organism. Students will then be allowed to access the data in ThingSpeak, a cloud-based server, that has been generated from the various Lab-in-a-Box modules throughout the room. The students will then select what they consider to be the most appropriate in-room micro-environment based on the data available. Students will also be given the opportunity to adapt the given micro-environments to an appropriate niche by utilizing heaters, humidifiers and alternative lighting and then make a final selection as to the best micro-environment (given or adapted) to successfully rear the organism. The assessment will consist of a presentation that describes and supports their selected micro-environment.

The unit will address several aspects of the Next Generation Science Standards and their foundational science and engineering processes and crosscutting concepts. The modeling of preferred habitat, engaging in an argument based on evidence and the cause and effect relationships between the various scenarios developed during this process incorporates the multi-dimensional demands of Next Generation Science teaching. Specifically, the unit will address the NGSS performance expectations listed in table 2.

## VII. College Life Science, Introduction to Using Data

The inquiry-based inferential design challenge tasked college life science education students to use real-time data to infer connections between multiple variables of habitat and their interconnectedness. Teams of 3-4 students were given real-time data collected by lab-in-a-box modules placed at different environmental locations and deduced the location of each sensor's environment given the data they were receiving. Teams then drew self-directed analyses between each lab-in-a-box's data to analyze the differences that exist between habitats (e.g. Temperature at each site, humidity at each site) as well as the connectedness of variables within habitats (e.g. Temperature vs Humidity, Temperature vs Light). The first deliverables from students were a hypothesis for the identity of each lab-in-a-box location with justification from data as well as a model to explain the variation found within and between sites using basic statistical approaches.

The design integration was completed in the second half of the lab component in which students brainstorm possible applications for this data in regards to an IoT framework. Such ideas could include air quality control or a data-based watering system. Students sketched a paper prototype of these applications including constraints that would have to be addressed during development.

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Table 1. Description of lesson one

| | | |
|---|---|---|
| **Standards**<br>**HSF.IF-** Interpreting functions<br>**HSN.Q-** Number and Quantity<br>**MS-ETS1-** Engineering Design | | |
| **Performance Expectations**<br>**HSF.IF.B.4** For a function that models a relationship between two quantities, interpret key features of graphs and tables in terms of the quantities and sketch graphs showing key features given a verbal description of the relationship.<br>**HSN.Q.A.1** Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.<br>**HSN.Q.A.2** Define appropriate quantities for the purpose of descriptive modeling.<br>**HS-ETS1-4**. Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem. | | |
| | | |
| **Dimension** | **Name and NGSS/CCSS code/citation** | **Specific connections to activity** |
| **Standards for Mathematical Practice** | creating a coherent representation of the problem at hand; considering the units involved; attending to the meaning of quantities, not just how to compute them; and knowing and flexibly using different properties of operations and objects.<br><br>**Model with Mathematics:**<br>identify important quantities in a practical situation and map their relationships using such tools as diagrams, two-way tables, graphs, flowcharts, and formulas. They can analyze those relationships mathematically to draw conclusions. | Students will be taking a story and creating a graphical representation by doing so, students will be reasoning abstractly and quantitatively<br><br>Students will be modeling with mathematics by creating graphs from stories. |
| **Science and Engineering Practices** | Using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. | Students will be analyzing graphical models to create a story. They will also be given a scenario and are expected to develop their own graphical model from the context of the scenario. |
| **Disciplinary Core Ideas** | **Developing Possible Solutions:**<br>Both physical models and computers can be used in various ways to aid in the engineering design process. | Students will analyze a model and create their own model. |
| **Crosscutting Concepts** | **Systems and System Models**<br>Use models (e.g., physical, mathematical, computer models) to simulate the flow of energy, matter, and interactions within and between systems at different scales. They can also use models and simulations to predict the behavior of a system, and recognize that these predictions have limited precision and reliability due to the assumptions and approximations inherent in the models. | Students will develop a model for the temperature of a room after time has passed, light v. time, distance v. time, and humidity v. time. |

Table 2. Description of lesson two

| **Standards**<br>**MS-LS1-** From Molecules to Organisms: Structures and Processes<br>**MS-LS2-** Ecosystems: Interactions, Energy, and Dynamics<br>**MS-ETS1-** Engineering Design | | |
|---|---|---|
| **Performance Expectations**<br>**MS-LS1-4**. Use argument based on empirical evidence and scientific reasoning to support an explanation for how characteristic animal behaviors and specialized plant structures affect the probability of successful reproduction of animals and plants respectively.<br>**MS-LS2-5** Evaluate competing for design solutions for maintaining biodiversity and ecosystem services.<br>**MS-ETS1-1**. Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.<br>**MS-ETS1-2** Engineering Design-Evaluate competing for design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.<br>**MS-ETS1-3**.Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.<br>**MS-ETS1-4**. Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved. | | |
| **Dimension** | **Name and NGSS code/citation** | **Specific connections to activity** |
| **Science and Engineering Practices** | **Planning and Carrying Out Investigations:**<br>Conduct an investigation to produce data to serve as the basis for evidence that meets the goals of an investigation.<br>**Engaging in Argument from Evidence:**<br>Use an oral and written argument supported by empirical evidence and scientific reasoning to support or refute an explanation or a model for a phenomenon or a solution to a problem. | Students will try to fit the organism to the most appropriate habitat to meet the goal<br><br>Students will present their findings to the class and support their conclusions. |
| **Disciplinary Core Ideas** | **LS1.A: Structure and Function:**<br>Plants and animals have both internal and external structures that serve various functions in growth, survival, behavior, and reproduction.<br>**LS1.B: Growth and Development of Organisms:**<br>Animals (organisms) engage in characteristic behaviors that increase the odds of reproduction.<br>**LS1.D: Information Processing:**<br>An organism's ability to sense and respond to its environment enhances its chance of surviving and reproducing.<br>**LS2.A: Interdependent relationships in ecosystems:**<br>Individual survival and population sizes depend on such factors as predation, disease, availability of resources, and parameters of the physical environment. | Students will have to be aware of the structural characteristics of the organisms.<br><br>Students will have to be aware of the behavioral characteristic of the organism.<br><br>Students will have to be aware of the sensory characteristics of the organism.<br><br>Students will have to take into account the predatory and resource parameters of a habitat. |
| **Crosscutting Concepts** | **Cause and Effect:**<br>Phenomena may have more than one cause, and some cause and effect relationships in systems can only be described using probability.<br>**Systems and System Models:**<br>A system can be described in terms of its components and their interactions.<br><br>Small changes in one part of a system might cause large changes in another part. | Students will consider a number of possible solutions relating to the cause and effect of certain habitat parameters.<br><br>The entire ecosystem of the habitat will need to be assessed in order to make a good choice.<br><br>Students will have to be aware that any change in the system (ie. night temperature change) can affect the organism.<br>. |

Table 3. Description of lesson three

| **Standards**<br>**HS-ETS1** - Engineering Design | | |
|---|---|---|
| **Performance Expectations**<br>**HS-ETS1-1**. Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.<br>**HS-ETS1-2**. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.<br>**HS-ETS1-3**. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.<br>**HS-ETS1-4**. Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.<br>**MP.2** Reason abstractly and quantitatively<br>**MP.4** Model with mathematics | | |
| **Dimension** | **Name and NGSS code/citation** | **Specific connections to activity** |
| **Science and Engineering Practices** | **Asking Questions and Defining Problems:**<br>Analyze complex real-world problems by specifying criteria and constraints for successful solutions.<br><br>**Using Mathematics and Computational Thinking:**<br>Use mathematical models and/or computer simulations to predict the effects of a design solution on systems and/or the interactions between systems.<br><br>**Constructing Explanations and Designing Solutions:**<br>Design a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.<br><br>Evaluate a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. | Students brainstorm potential problems that might use the data collected from Lab-in-a-Box and explain what constraints may exist for said problem. |
| **Disciplinary Core Ideas** | **ETS1.A: Defining and Delimiting Engineering Problems:**<br>Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them.<br><br>Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities.<br><br>**ETS1.B: Developing Possible Solution:**<br>When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts.<br><br>Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs.<br><br>**ETS1.C: Optimizing the Design Solution:**<br>Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. | |
| **Crosscutting Concepts** | **Systems and System Models:**<br>Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions— including energy, matter, and information flows— within and between systems at different scales. | |