SMART Buoys: Integrating Data Visualization and Design to Reduce Ocean Life Casualties

Introduction

In recent years, the impact humans have had on the world, and specifically the world's oceans and marine life, have surfaced as one of the most continuously discussed topics in news feeds and other media outlets (Elliott, 2018). Specifically, current research and well-known stories have detailed the disastrous effects—direct and indirect—humans have had on the oceans (Ocean Priorities, 2009; Weiss & McFarling, 2006; Yong, 2019). The impact of human activity on marine life through unsustainable actions, recreational activities, pollution, and consumption patterns continues to lead to calls for attention and action of individuals worldwide. Many organizations, researchers, and individuals have sought to raise awareness of the importance of ocean conservation and sustainable actions in the hopes of counteracting the impacts of human-environment interactions by shaping how humans view, use, and manage the ocean environments (United Nations, 2019; United Nations Department of Economic & Social Affairs, 2014).

Today, the world's oceans show the results of many subtle and profound changes (Davidson et al., 2012); for example, recent research shows that no area of the ocean remains completely unaffected by human influences (Halpern et al., 2008). Further, investigation shows that approximately forty percent of our vast oceans are strongly affected by multiple human impacts (Halpern et al., 2008). These include—but are certainly not limited to—pollutants (i.e., chemical contaminants, debris, and even sonar noise), by-catch, shipping, overharvesting, global warming, ocean acidification, and the altering of food webs (Halpern, et al., 2008; Schipper et al., 2008). Negative impacts to natural environments and wildlife, such as these, continue to increase globally as the demand for space and resources continues to grow in order to accommodate the world's population.

Oceans overall continue to be affected by changes in temperatures, acidity levels, and even available nutrients; these impacts transition to the living things found within these waters. Specifically, marine mammals—key players in our ecosystems—have found themselves in the crosshairs of many of these changes (Schipper et al., 2008). The International Union for the Conservation of Nature (IUCN) currently identifies one-fourth of marine mammals to be at risk of extinction (Davidson et al., 2012), and estimates show that approximately three-fourths of marine mammals experience high levels of human impact within their geographic ranges; impacts from activities such as fishing, shipping, pollution, sea surface temperature change, ocean acidification, invasive species, oil rigs, and human population density (Schipper et al., 2008).

Lattitude	Longitude	Altitude
40.51298	-86.715597	793.89
40.513141	-86.715513	796.09
40.513138	-86.71528	796.49
40.513241	-86.714847	802.88
40.51336	-86.714657	800.98
40.513488	-86.714463	799.59
40.513608	-86.714285	798.68
40.513722	-86.714113	799.27
40.513842	-86.713926	797.88
40.513692	-86.714062	797.75
40.513535	-86.71421	796.68
40.513393	-86.714347	795.8
40.513251	-86.714486	794.6
40.512976	-86.7146752	791.56
40.512828	-86.714891	790.8
40.512692	-86.715019	791.63
40.512549	-86.715155	794.15
40.512457	-86.715361	793.75
40.512501	-86.71557	793.44
40.512667	-86.715502	793.48
40.512666	-86.715273	793.32
40.512827	-86.714946	795.89
40.51293	-86.715142	794.95
40.51293	-86.715379	794.69
40.51298	-86.715597	793.89
40.512976	-86.714752	791.56

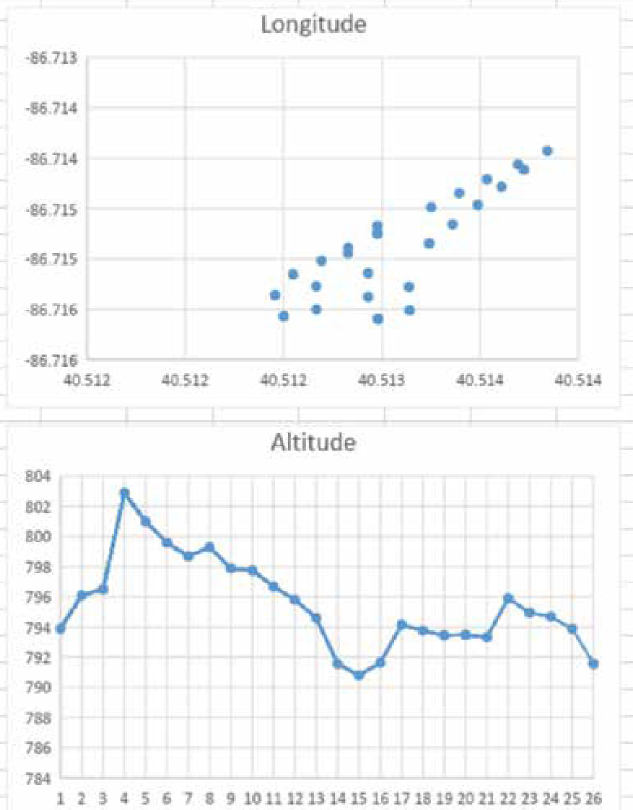

Figure 1.

Among marine mammal mortality rates, the single greatest threat has been found to be accidental mortality (i.e., vessel strikes and fisheries' by-catch [unwanted catch collected during the fishing of other species]) (Schipper et al., 2008). In Florida, one case of impact became the subject of multiple news stories, as it was found that one-fourth of all recorded manatee deaths had resulted from manatees being struck by boat props (Calleson & Frohlich, 2007). Manatees, however, are not the only documented cases of high accidental mortality rates within marine mammal populations. Every year thousands of seals are also killed by boat props—casualties resulting from boats inadvertently speeding over feeding seals, with often fatal results. Although these casualties are not as drastic in numbers within all marine species, the issue of ecosystems being affected by human activity (such as boating) is universal and has had an adverse effect on the environment and marine life populations (National Ocean Service, 2019).

Innovations for Saving Marine Wildlife

Over time, a range of approaches and methods have been used in an attempt to study the behavior and movement of marine animals. Only recently however, has data been provided and available publicly for a variety of species. Sharks, for example, are studied using pop-up archival tags (PAT)—a type of tag that collects various information about specific species patterns, such as the depth of dives (calculated from pressure), ambient light used to estimate and track locations, as well as internal and external body temperature (Musyl et al., 2011). New techniques and devices such as these are advancing our understanding of animal species and their environmental patterns, which may provide individuals with valuable information needed to continuously create and innovate methods of aiding marine wildlife.

As GPS technology has resulted in mapping and tracking data for a variety of marine life, it is possible that accidental mortality incidents among marine animals can be reduced as boaters are made more aware of their surroundings. For example, it is feasible that GPS technologies could be used to alert boaters to slow down around, or avoid, high-population-density areas of marine mammals.

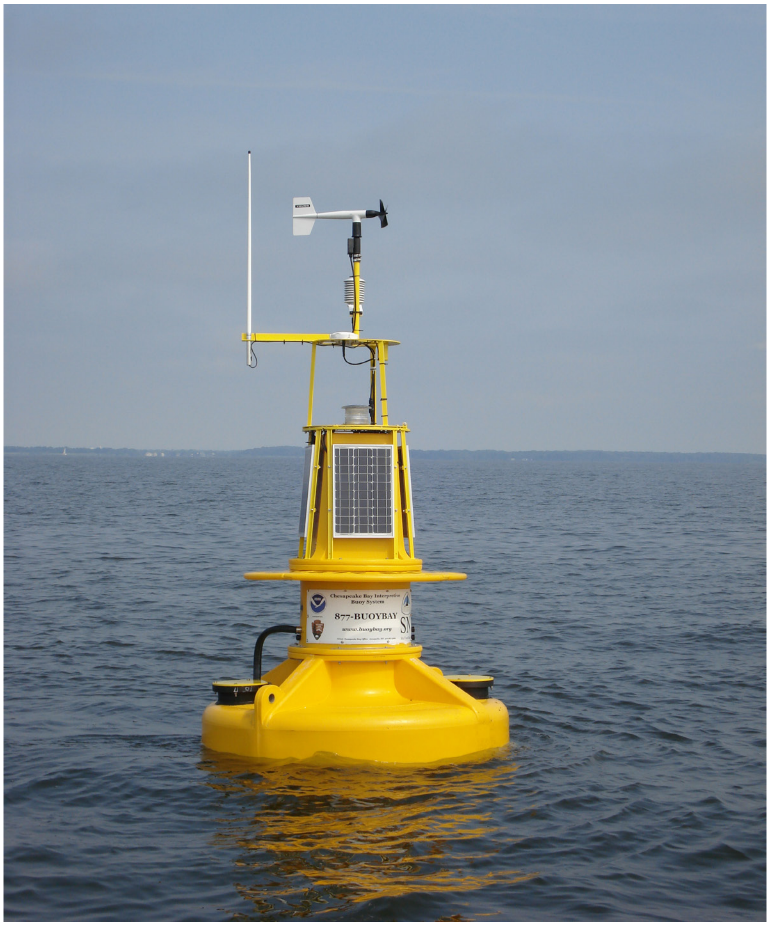

Figure 2.

To build upon this concept, the authors developed a lesson to provide students with the opportunity to engage in core design practices that are informed through data visualization techniques of marine wildlife patterns to reduce the amount of marine-life casualties. In this lesson, students are tasked with creating a solution—through the use of engineering design—to address one of the greatest threats to marine animal species by reducing boating accidents. Specifically, students are tasked with designing a buoy that will provide boat drivers with a warning about nearby marine life so they can respond appropriately. An overview of the lesson can be found in Table 1, with the full Lesson Plan included as Table 2.

Engineering Classroom Connections

In this lesson, students engage in analyzing generated data from OceanTracks.org (Figure 1), identifying patterns and creating a data visualization model based on their own research of scientific data in order to inform design decisions. Students consider the interactions from their chosen combination of variables involving marine wildlife movement/patterns, human impacts, and environmental factors in order to develop a visual representation of a geographic location with high marine wildlife activity overlapping regions of high human impacts. Students are challenged to use their newfound insights derived from their visual model to drive design decisions as they design and prototype an automated buoy for a specified "ocean" region in the hopes of alerting boaters of nearby marine life.

This lesson incorporates current and relevant global issues in the hope of providing a way to engage students in a multitude of engineering and technical concepts, while also developing crucial applied skills necessary for the 21st century, such as critical thinking, information literacy, and technology literacy (Dean et al., 2010). Additionally, the many parallels between the engineering and visualization processes may reinforce critical areas such as collaboration, creativity, imagination, critical thinking, and problem solving (Byrd, 2018). As students work through the engineering process and visualize the data associated with the project, this lesson facilitates informed decision making with visual representation of the data (created by the student) to support those decisions and further reinforce engineering and data visualization principles.

The lesson includes a classroom design challenge and the associated lesson designed to integrate STEM content through the authentic and socially-relevant context of a current global issue, marine-life causalities. It is clear that news stories and policies are reflecting the need for individuals to be informed of the impacts humans have on the earth, not only on a large scale, but also through small, everyday choices. Integrating the authentic and socially relevant context of a global issue within lessons not only aids to engage students, but also promotes the importance of working towards imagining, designing, modeling, and even testing potentially viable solutions to the problems they see—and hear of—around them.

Conclusion

It is the authors' hope that providing an engineering challenge that requires the use of data to inform design decisions will call attention to the value and advantages that data collection and analysis can provide to students during their decision process. While the processes of tinkering and trial and error within an engineering/technology classroom are common, it is also important for educators to provide students with opportunities in which research and data visualization can be used to inform and drive design decisions. It is crucial that students are knowledgeable about—and develop experience with—a multitude of processes and principles that they can employ to approach the challenges and problems they hope to solve. Therefore, providing socially relevant design opportunities for students, while also incorporating challenges requiring research and data, can hopefully result in a more effective solution than what could be achieved through simple trial and error.

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Figure 2.

SMART Buoy Assignment

Description: Each student will use researched data to create a data visualization model that will be used to inform their decisions as design, model, and create a model smart buoy. Students will use Tableau (or other interactive data visualization software) to create a data visualization model. Students will then use CAD software to model their Buoy, and a 3D printer to print the prototype of the Buoy.

Data Visualization Model Scoring Rubric:

Item	Description	Pts Possible	Total
Deliverables	Detailed research and data (acquired through OceanTracks) is produced and turned in. Research contains all necessary components including several graphs, and evidence supporting the chosen location of the Smart Buoy placement.	60	
Performance	Model effectively functions through the use of an interactive data visualization software	20	
Model	Student model effectively communicates the following: • Student progress through the data visualization process • Insights achieved through the use of data visualization	20	
TOTAL		100	

Smart Buoy Rubric

Item	Description	Pts Possible	Total
Design	Student's Buoy Design must: • Be informed by the data communicated through their Data Visualization model • Created through CAD Software	20	
Model	Physical prototype must meet each of the following criteria: • Must float within provided water (pool, bucket etc.) • 3D printed • Include cavities for wires, motors, sensors etc.	25	
(SMART) Automated controls	Automated control system for the SMART Buoy (using either the Arduino/Genie control board) must meet 2 of the following criteria: • Use of temperature sensors to activate motors • Use of timer to activate motors • Use of sensors (temperature, light etc.) to detect nearby marine life Additionally, each Buoy should include an LED to warn individuals of nearby marine life. The LED must be: ▪ Programmed to Blink ▪ Strategically placed on buoy to be easily visible	25	
Wiring	Electrical wiring must be added to power: • Warning light (1 Blinking LED) • Motors for moving the buoy within the water • Any additional motors, sensors, LEDs & control board(s)	20	
Performance	Smart Buoy functions as outlined in the assignment description	10	
TOTAL		100	

Table 1. Reducing Ocean Life Casualties Through SMART Buoys Lesson Overview

Lesson Purpose:
In this lesson, students engage in analyzing data, identifying patterns, and creating a data visualization model based on their own collection of scientific data. Students are then challenged to use the insights from their data visualization models in order to drive their design decisions as they create, automate and strategically place a buoy within the "ocean" in the hopes of alerting boaters of nearby marine life. This lesson incorporates current global issues in the hope of providing a way to engage students in a multitude of engineering or technical concepts, while also developing crucial skills necessary for the 21st century, such as critical thinking, analyzing and interpreting data, and relaying findings to others.

Lesson Duration: 20 Hours (14 Class Periods)

Engineering Core Concepts & Sub-Concepts:

Research
- Information Gathering
- Data Collection & Organization Methods

Data Collection, Analysis, & Communication
- Techniques of Data Collection (e.g. sampling methods)
- Data-Driven Decisions
- Creating Graphs & Technical Documents
- Reporting Data

Computational Tools
- Spreadsheet Computations (e.g. Microsoft Excel)
- Data Visualization

Computational Thinking
- Programming & Algorithms
- Script Programming Languages

Decision Making
- Evidence/Data-Driven Decisions

Global or Local Issue:
Boating and fishing have left an adverse effect on the environment and marine life populations. Through the use of engineering design, students may be able to create a device that reduces boating accidents, and provides drivers with a warning about nearby marine life so that they may respond appropriately and help to protect both the environment and the boats themselves (Calleson & Frohlich, 2007).

Connected STEM Standards:

Standards for Technological Literacy
- *Standard 1*: Students will develop an understanding of the characteristics and scope of technology
  - **Benchmark F:** New products and systems can be developed to solve problems or to help do things that could not be done without the help of technology.
- *Standard 3*: Students will develop an understanding of the relationship among technologies and the connections between technology and other fields of study.
  - **Benchmark F:** Knowledge gained from other fields of study has a direct effect on the development of technological products and systems.
- *Standard 12*: Students will develop the abilities to use and maintain technological products and systems.
  - **Benchmark J:** Use computers and calculators in various applications

STEM Standards: (NGSS)
- **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.
- **HS-ESS3-4.** Evaluate or refine a technological solution that reduces impacts of human activities on natural systems

Learning Objectives:
- I can create a data visualization model based on large data sets.
- I can use data visualization software to communicate insights from my research.

- I can use findings from the analysis of data to inform my design decisions.
- I can automate systems to solve a problem using a microcontroller.

Enduring Understanding(s):

- Data visualization is used in decision making processes and matrices in career fields and in higher education.
- The data visualization process is flexible and includes multiple stages.
- Data can be used to inform design decisions.
- The goal of data visualization is to provide individuals with insights.

Driving Question(s):

- What is the purpose of data visualization?
- How can I effectively communicate insights from my research with others?
- How can we utilize the data visualization process in engineering design problems?
- How can we use data to make informed decisions when designing a product?

Required Student Prior Knowledge & Skills:

Integration of students' prior knowledge is critical in any successful lesson. In order to successfully build upon their knowledge, the following concepts are expected to be understood prior to beginning this lesson:

- Mathematics
  - Ability to produce and analyze diagrams
  - Concept of correlations
- Engineering/Technology
  - Ability to choose correct tools for given task
  - Programming basics
  - Ability to use CAD software
- English
  - Read and appropriately interpret researched information
  - Explain and elaborate on researched information
  - Effectively communicate through clear writing
- Computer Skills
  - Technological literacy in order to navigate OceanTracks Software and learn Tableau

Tools / Materials / Equipment

The following is a list of materials and equipment necessary for successful delivery of this lesson plan:

- Computers with internet access and presentation software x 20
- Tableau education keys x 20
- Arduino set x 5 (Arduino Starter Kit or any Arduino product)

  Each Start Kit contains each of the following:
  - Project Book x 1
  - Arduino / Genuino Uno x 1
  - USB cable x 1
  - 400 Point Breadboard x 1
  - Solid core jumper wires x 70
  - Easy-to-assemble wooden base x 1
  - 9v battery snap x 1
  - Stranded jumper wires (black) x 1
  - Stranded jumper wires (red) x 1
  - Phototransistor x 6
  - Potentiometer 10kOms x 3
  - Pushbuttons x 10
  - Temperature sensor [TMP36] x 1
  - Tilt sensor x 1
  - Alphanumeric LCD (16x2 characters)
  - LED Bright white x 1
  - LED RGB x 1
  - LED red x8
  - LED green x 8
  - LED yellow x 8
  - LED blue x 3
  - Small DC motor 6/9v x 1
  - Small servo motor x 1
  - Piezo capsule [PKM17EPP-4001-B0] x 1
  - Optocouplers [4N35] x 1
  - Mosfet transistors [IRF520] x 2
  - Capacitors 100uF x 5
  - Diodes [1N4007] x 5
  - Transparent gels (red, green, blue) x 3
  - Male pins strip (40x1) x 1
  - Resistors 220 Ohms x 20
  - Resistors 560 Ohms x 5
  - Resistors 1 kOhms x 5
  - Resistors 4.7 kOhms x 5
  - Resistors 10 kOhms x 20
  - Resistors 1 MOhms x 5
  - Resistors 10 MOhms x 5

Table 2. Reducing Ocean Life Casualties Through SMART Buoys Lesson Plan

Engage: tell students they will be learning about human impacts threatening ocean wildlife ~ 90 minutes (1 class period)

• Begin by having the class brainstorm the following as a group:
    • What human behaviors/impacts (direct and indirect) threaten marine life?
    • What marine animals are most affected by these behaviors/impacts?
    • How much of the ocean is actually affected by human impact?
Prompt students to consider impacts such as pollution, overfishing, global warming, boating, littering etc.
• Challenge students to consider: "How do we know all of this?" (How do we know humans are having an impact on oceans and marine life? How do we know which animals are being affected? How do we know how much of the ocean is being affected?)
*Ultimately, you want students to realize they obtain their information about current events from news stories that cover **developing data/information**, often found through emerging and continued **research**.*

Explore: Task students with searching through new articles and sites in order to investigate some of the human impacts, and affected animals from the class' brainstormed list. ~ 180 minutes (2 class periods)

Begin by having laptops distributed at students' desk. Direct all students to begin researching marine life mortality as well as exploring *OceanTracks.org*. They should explore the data collected from the various marine mammal species and locations. *Consider teaching students the specifics of the various tools or allowing them to explore and discover these on their own.
Identify specific guidelines for research if needed. Some guidelines could include:
    • Identifying news/ research pertaining to animals native to their community/ surrounding area
    • Identifying news/ research related to the four animals that will later be researched in depth (Bluefin Tuna, White Sharks, Elephant Seals or Laysan Albatross)
    • Identifying news/research related to a specific human impact (i.e. pollution or fishing)
Walk around while students are working, and aid individuals who may be struggling with researching techniques (filtering through articles based on dates, or credibility of the source etc.), as needed.
• After the allotted time, have students come together in order to share their findings.
Allow students to drive the discussion. Students should learn about other human impacts or affected animals they did not research or know about.
• Prompt students to consider the following:
    • Were you able to easily find stories related to those animals you thought would be affected by human impacts? If so, why could that be?
    • Did anything surprise you as you read through or heard about the news articles?
    • Were there any human impacts or affected animals we did not identify during our initial brainstorm?
    • How recent were the news reports you found? Does the publication date matter?
Use students' research and responses to address any misconceptions and assess comprehension of the covered material.

Explain: Summarize new and prior knowledge while addressing any misconceptions the students may hold. ~90 minutes (1 class period)
• After the discussion take time to provide the context of the lesson and transition students to the continuation of the unit on research, data and design. "Today we will focus on Data Visualization, and how data visualization models are used to provide insights during decision-making processes. This lesson will aid you as you begin to consider how you could best design your buoy to prevent marine wildlife casualties."

- Introduce students to data visualization by reviewing the 7-stages of the visualization process and the goal of visualization: *to provide insights*. Teachers can refer to the DataVisualization.pptx as an introduction.

  The PowerPoint includes:
  - What is Data Visualization?
  - What is the purpose/ benefit of using Data Visualization?
  - 7 Stages of Data Visualization
  - Walkthrough of process using OceanTracks

- Explain to students that they will be tasked with creating and "placing" a SMART Buoy within the ocean in order to help prevent marine animal casualties (like those they researched) due to boating accidents. Students are expected to design this device using research and data to inform their decisions, just as organizations, businesses and engineers do during their decision-making processes.

  Students design decision should be based on research and data collection that they ultimately share with others in order to gain approval/ support for their idea. Students should use data visualization models in order to effectively communicate insights.

Take time to answer questions and clarify any misconceptions students may have.

Engineer: Engage students in applying their knowledge and skills using the engineering design process to identify a problem and to develop/make/evaluate/refine a viable solution.

~ 720 minutes (8 class periods)

- In this activity (Smart Buoy Assignment), students are asked to use *OceanTracks.org* to identify a specific marine mammal to research. Students use *OceanTracks.org* to identify tendencies and patterns in the mammal's behavior based on the GPS-tracking devices. Using the gathered data, student will employ the data visualization process to create a model using data visualization software. Later, students will use their created model to make predictions and decisions regarding the design of their Smart Buoy.

  Students' research should include:
  - Chosen marine animal from *OceanTracks.org*
  - Data from 8 different individuals from the specific marine animal (i.e. seal)
  - Outline of the daily behavior, feeding characteristics, and unique traits of the chosen animal
  - Data points from three overlays (movement, speed, temperature, human impacts etc.)
  - Data points across a time period that spans a minimum of six months' worth of data

Take time to review directions, answer questions and clarify any misconceptions students may have. For further resources in what this data collection should look like utilize Module 1 and 3 from OceanTracks.org in the resources section in the end of the course plan.

- As they conclude data collection, students should begin to interpret the data in order to identify possible insights.

  Students should analyze their collected data and consider the following:
  - What does the data look like/represent?
  - What patterns do you notice?
  - What does the data "show"?
  - What do you think the data means?
  - What can you conclude about the data?
  - What generalizations do you think you can make based on your data/observations?

As students are working, remind them of the importance of documenting assumptions and thoughts they have about the data as they work through the visualization process. Documenting their assumptions will help provide rational for decisions and choice of data points, as well as identify advantages and limitations of their choice.

- After completing their report with data collection, students are encouraged to create data visualization models utilizing Tableau (or similar) software. Data visualization software can create easily accessible and interactive data to best display the information about the specific species they observed through *OceanTracks.org*.

If Tableau is unable to be obtained for students or classroom use it is possible to use Excel software, however Tableau provides more visualization options and features than Excel.

- After completing their Data Visualizations, students can begin to design and create their buoy.
- Students utilize their models to make predictions and decisions regarding the design of their Smart Buoy. Using their predictions students should design, 3d print, and ultimately automate their Smart buoy using a microcontroller with both inputs and outputs.

Take time to review directions, answer questions and clarify any misconceptions students may have.

- Students will begin by deciding which sensors will be used to fulfill the required criteria.

Remind students of the importance of using their research and data to make these design decisions.

- Students will then begin to design their Buoy using CAD software. Students' design will be used to create a physical prototype to later be tested.

  The physical prototype should:
  - Include cavities for wires, motors, sensors etc.
  - Float within the provided body of water (pool, bucket etc.)
  - Be printed using a 3D printer and appropriate materials

As students work through this part of the lesson, be sure to approve designs before students begin to print in order to correct any errors and help them avoid the need for many reprints.

- Once their design has been approved, students can then print their buoys using a 3D printer.
- After completing the design, and printing of their buoys, students can begin to wire and create an automated control system in order to create the SMART Buoy. Students can use an Arduino/Micro:Bit control board and provided materials (motors, sensors, etc.) to complete the activity.
  - Students are asked to meet 2 of the following criteria:
    - Use of temperature sensors to activate motors
    - Use of timer to activate motors
    - Use of sensors (temperature, light etc.) to detect nearby marine life

    Additionally, each Buoy should include an LED to warn individuals of nearby marine life.

    The LED must be:
    - Programmed to Blink
    - Strategically placed on buoy to be easily visible
  - Electrical wiring must be added to power:
    - Warning light (1 LED)
    - Motors to enable buoy to move
    - Any other motors, sensors, & control board(s)

Note: This lesson assumes students have experience with microcontrollers, and programming basics. Students who are unfamiliar with these can be introduced to a programming language through online block coding games until they are comfortable with programming a microcontroller.

Evaluate: Allow students to evaluate their own learning and skill development in a manner that enables them to take the necessary steps to master the lesson content and concepts.

~ 180 minutes (2 class periods)

- Students should be evaluated on both their designed/automated Buoy and Data Visualization Model. Several potential approaches to evaluation are listed here:

1. Points will be calculated based on:
   1. Detailed research and data (acquired through OceanTracks)
   2. Accurate reflection of submitted research
   3. Use of interactive data visualization software to create data visualization model
   4. Evidence of using research and data to inform buoy design
   5. Use of appropriate materials to create functional buoy
   6. Use of electrical wiring to power specified items
   7. Use of an Arduino/Genie control board to automate specified actions
2. Assessment Instrument - Demonstration of Project Criteria

Students are expected to demonstrate the following to the instructor and class:

2. Video or demonstration of smart Buoy running and completing the tasks described in the Smart Buoy worksheet
3. Presentation reflecting each step of the engineering design process as well as the data visualization process that allowed informed decision making
4. Screenshots of project code (e.g., Arduino, Micro:bit)
5. Completion of project criteria

3. Assessment Instrument - Design Journal (50 points)

Students are expected to document work within a journal. The following criteria apply to the design journals:

- Completion (*25 Points*)

  Points will be calculated based on:

  - Code from temperature sensor tutorial
  - Brainstorming for Smart Buoy
  - Data Visualization of chosen species
  - Design Sketches
  - Evidence of a completed product
  - Journal made up of their original work
  - Required documents are presented and accessible

- Data Visualization Model (*25 Points*)

  Points will be calculated based on:

  - Does the visualization provide insights and facilitate the decision-making process?
  - Is the visualization clear and intentionally structured in an easy-to-understand way?
  - Is the visualization process accurate and following scientific rigors?

Note. Lesson format adapted from Grubbs & Strimel (2015).